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Sports bra design for active women

Kelly-Ann Bowles

University of Wollongong

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Sports bra design for active women

A thesis submitted in fulfilment of the
requirements for the award of the degree

Doctor of Philosophy

from

University of Wollongong

by

Kelly-Ann Bowles
BSc (Human Movement Science)

School of Health Sciences

2012
Dedication

To my loving husband John,

your constant support and encouragement gives me the confidence to achieve anything. Without your love, support and understanding, completing this thesis would not have been possible. Now it is your turn to embark on your academic plan.

To my parents, Jill and Darryl Page,

you have always encouraged me to work hard and set goals. Your assistance and support through school and my undergraduate degree laid the stepping-stones for this thesis. Your continual emotional support and interest over the years gave me the confidence to take this further step. Dad, I am so sad that you will not be there to see me graduate, but I know you will continue to support me from above.

And finally to my beautiful daughter Grace and handsome sons Liam and Evan,

although the plan of finishing this thesis before you were all born did not happen, we got there eventually. You are all the most beautiful gifts and I hope that you are constantly surrounded by people who encourage you to be the best that you can be in everything you wish to pursue.
Declaration

I, Kelly-Ann Bowles, declare that this thesis, “Sports bra design for active women”, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Health Sciences, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged in this thesis. The thesis has not been submitted for qualifications at any other university or institution.

________________________
Kelly-Ann Bowles

14th November 2012
Publications

This thesis includes chapters that have been written as the following journal articles:


As the primary supervisor, I, Professor Julie Steele, declare that the greater part of the work in each article listed above is attributed to the candidate, Kelly-Ann Bowles. In each of the above manuscripts, Kelly-Ann has contributed to study design, was solely responsible for data collection and data analysis, and was largely responsible for data interpretation. The candidate wrote the first draft of each manuscript and Kelly-Ann was then responsible for responding to the editing suggestions of her co-authors. The co-authors, Julie Steele (Chapter 2-5), Bridget Munro (Chapter 2 and 3) and Rungchai Chaunchaiyakul (Chapter 4) were responsible for assisting in study design, data interpretation and editing in the manuscripts. Kelly-Ann has taken the lead role in submitting each manuscript for publication to the relevant journals, and she has been primarily in charge of responding to reviewer’s comments, with assistance from her co-authors.

Kelly-Ann Bowles
Candidate
14th November 2012

Professor Julie R Steele
Primary Supervisor
14th November 2012
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Abstract

Background: Exercise induced breast motion and the associated breast pain, particularly in larger breasted women, can be severe enough to discourage some of these women from participating in sport and exercise. To ensure all females have the opportunity to comfortably participate in, and therefore reap the health benefits associated with regular physical exercise, it is imperative that we understand factors that enable sport bras to limit breast movement and associated pain, without negatively affecting physical performance or causing discomfort to the bra wearer.

Thesis Aim: The aim of this thesis was to identify factors that influence breast support choices made by Australian females when they participate in physical activity, and then systematically investigate the factors that may deter females from using sports bras in order to develop recommendations for improving sports bra usage.

Approach: A mail out survey was firstly used to analyse consumer usage of sports bras in a general Australian female population (Chapter 2), and to determine the deterrents to their use in this population (Chapter 3). Based on the survey results, two subsequent studies were designed to systematically investigate two factors that the survey respondents disliked about current sports bras: (i) the perceived tightness of sports bras around the wearer’s torso (Chapter 4); and (ii) perceived problems associated with sports bra shoulder straps digging into and/or slipping off the wearer’s shoulder (Chapter 5).

Results: The survey revealed that sports bras were not the most common breast support choice during physical activity, with only 41% of respondents indicating they currently wore a sports bra during physical activity (Chapter 2). Furthermore, the main sports bra features that respondents “extremely disliked” were the shoulder straps digging into the shoulder (34%) and the shoulder straps slipping off the shoulder (34%). From a design perspective, respondents also indicated that the perceived tightness of the sports bra around the chest was another disliked feature that deterred them from wearing a sports bra (Chapter 3).

When investigating the perceived tightness of sports bras around the wearer’s torso (Chapter 4), it was revealed that although the sports bra imparted significantly
more pressure on the torsos of the females with smaller breasts, when compared with
the fashion bra, this increased pressure did not significantly affect measured lung
volumes or bra comfort scores. Bra size (or breast hypertrophy), however, affected
maximal exercise ability, as well as some temporal measures of resting and sub-
maximal respiration, whereby the participant’s with larger breasts displayed lower
maximal exercise ability and faster rates of inspiration.

Investigating the effects of modifying bra shoulder strap orientation (Chapter 5)
revealed that the cross-back strap orientation significantly reduced vertical breast
displacement (VBD) compared to the no strap condition. However, there was no
significant difference between the traditional and cross-back strap orientations in their
ability to reduce VBD and both strap orientations successfully reduced breast pain
compared to the no strap condition. Although the cross-back strap orientation resulted
in some higher force and mean pressure values at the strap-shoulder interface compared
to the traditional strap orientation, no significant difference was found between the two
strap orientations. Unexpectedly, inserting a bra strap cushion under a bra strap was not
effective in decreasing the pressure at the bra strap-shoulder interface due to design
flaws that prevented the strap cushion from adequately increasing the strap-shoulder
contact area.

**Major Conclusions:** Sports bras were not the most common breast support choice
during physical activity, whereby factors such as perceived tightness around the chest
and the shoulder straps digging into or slipping off the shoulder were identified as
deterrents to the use of sports bras. However, no significant restriction to respiratory
mechanics during exercise was found when participants wore a correctly fitted
encapsulating sports bra, compared to other forms of breast support. In addition, if the
bra is correctly fitted, using a cross-back strap orientation is a viable option to prevent
shoulder straps from slipping off the shoulder of the wearer, without affecting vertical
breast support. Further research is warranted to look at strategies to prevent sports bra
straps digging into the shoulders of the bra wearer in order to improve sports bra usage
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Chapter 1

The Problem

INTRODUCTION

Increasing levels of obesity are a growing concern in modern society, mainly due to the associated negative health implications and escalating costs to the community. In the 2007-08 National Health Survey (Australia), 56% of adults reported a body mass index (BMI) that would classify them as overweight or obese [1]. Compared to data from five surveys that were implemented over the previous 20 year period, steady increases have been seen in the proportion of the population classified as overweight or obese from 38% in 1989-90, 44% in 1995, 50% in 2001, 54% in 2005, to 56% in 2007-2008. The most concerning increase was the proportion of the population that reported a BMI that would classify them as obese; this had more than doubled from 9 to 21% over the 20 years of the surveys. In a separate report it was estimated that the financial cost of obesity in Australia in 2008 was $8.3 billion [2], with the cost of overweight equalling an additional $10.5 billion [3].

In addition to the financial costs associated with the obesity epidemic, the health implications of the disease are substantial. Obesity has been linked to a large range of medical conditions including Type 2 diabetes, coronary heart disease, hypertension, high cholesterol, asthma, joint pain and sleep apnoea [4-8]. In addition to the above-mentioned diseases, a 2003 study in the United States of America (USA), involving more than 900,000 people who were over the age of 30 years, reported a significant positive linear relationship between BMI and risk of a large range of cancers, including breast cancer, ovarian cancer, cervical cancer and uterine cancer [6]. The report highlighted that study participants with a BMI over 40 had death rates from all cancers
52% (men) and 62% (women) higher, when compared to men and women within the normal weight range (BMI: 18.5 – 24.9) [6]. It is believed that the higher cancer rates in overweight women may be associated with the production of additional estrogen within adipose tissue, with higher levels of estrogen exposure linked with the above-mentioned cancers [9]. It is therefore suggested that, in association with a healthy diet, increasing participation in physical activity is of paramount importance to reduce current obesity trends and the associated higher cancer risk.

Physical activity not only lowers body fat levels through changes in metabolic rate, but also results in many physical and psychological benefits such as improvements in cardiovascular fitness and overall well-being [10]. For example, in a survey of approximately 40,000 Australian women, results indicated that the likelihood of experiencing tiredness, back pain, constipation and difficulty sleeping decreased as physical activity increased [5]. In younger women, the likelihood of reporting menstrual symptoms, such as premenstrual syndrome and severe menstrual pain, was reduced by 13 to 15% in those who reported higher levels of physical activity compared to their less active counterparts. It was also noted that the likelihood of reporting heavy menstrual bleeding was 25% lower in the higher physically active subjects. In the middle aged (45 to 50 years) and older (70 to 75 years) participant groups, the reporting of stiff and painful joints was substantially reduced (15 to 40%) in more active women, as was the occurrence of medical conditions such as hypertension and osteoporosis [5]. In addition, participation in physical activity has been shown to decrease the side effects associated with menopause including hot flushes, fatigue, insomnia and impatience [11]. Most of these positive results were apparent when the study participants were involved in physical activity of a moderate intensity level most days of the week.
Other important health benefits have been reported as a result of women participating in physical activity. For example, some forms of physical activity can decrease injury rates as participating in weight bearing exercise, in combination with adequate estrogen levels, can increase bone strength [12]. In addition, psychological well-being and physical activity have also been linked, whereby Lee and Russell [13] found a significant relationship between participating in physical activity and a high level of emotional well-being in older women. The authors suggested that when physical activity levels were decreased, negative changes were seen in emotional well-being. These results are consistent with a National Center for Chronic Disease Prevention and Health Promotion (USA) report [14], which suggested that physical activity could relieve symptoms of depression and anxiety, in turn, leading to a better quality of life through enhanced psychological factors such as self-concept, self-esteem and mood. This is of great importance as women have been shown to report depression and psychological distress more commonly than men [15]. Therefore, health professionals and other relevant agencies should encourage individuals within the community, especially females, to become more physically active and determine ways to foster the ease at which individuals can participate in physical activity.

When compared to 1997, the 2000 Active Australia National Physical Activity Survey reported an increase in the percentage of the population aware of the health benefits of physical activity. Unfortunately, despite this increase in awareness, actual participation in physical activity decreased over the 1997 to 1999 time period with 43% of the survey population aged between 18 and 75 years not participating in physical activity to a level recommended to achieve health benefits (at least 150 minutes per week of moderate-intensity aerobic physical activity throughout the week; at least 75 minutes of vigorous-intensity aerobic physical activity throughout the week, or an
equivalent combination of moderate- and vigorous-intensity activity) [16]. Even more concerning was the finding that 15% of the survey population did not participate in any leisure time physical activity, resulting in increases in physical inactivity rates from 38% in 1997 to 43% in 1999/2000. More recently, the 2007-2008 National Health Survey (Australia) suggested that 72% of Australians aged over 15 years were classified as sedentary or having low exercise levels [1].

When examining data reported for males and females separately, the National Health Survey results from 2007-2008 found that women were more likely to be sedentary or have low activity levels (73%) when compared to their male counterparts (66%) [1]. Although the decline in physical activity over the years has been evident in both sexes, females have displayed a greater decline from 61% of the population participating in sufficient amounts of physical activity in 1997, to 54% in 1999. Participation in regular vigorous intensity physical activity was more common in men (11%) compared to women (6%), with women highlighted as an ‘at risk’ group as a result of their decreased likelihood to participate in regular physical activity [17].

When developing strategies to encourage participation in physical activity, physiological and anatomical differences between the sexes should be acknowledged, particularly those between-sex differences that can pose unique barriers to females participating in physical activity. For example, Brown and Miller [18] suggested that numerous women reported avoiding participation in sport and exercise due to problems associated with leaking urine. It has also been suggested that some women refrain from participating in physical activity due to the pain and/or embarrassment associated with excessive breast motion [19]. Although the medical implications of excessive breast motion and resultant breast pain are not known, the fact that pain is apparent suggests that some damage may be caused to internal structures of the breast tissue as a result of
excessive breast motion. This possible tissue damage, along with the negative health implications associated with a lack of physical activity due to breast motion and resultant breast pain, necessitate the development of strategies to provide adequate breast support during physical activity.

As the female breast contains no supportive muscle or bone (see Figure 1) [20], breast tissue is relatively free to move over the chest wall, especially during motion of the torso, such as that which occurs during physical activity. Some authors have stated that skin provides most of the anatomical support for the breast [21]. Others claim that the thin bands of fibrous tissue that divide the breast lobules and attach to the deep fascia of the pectoralis muscles, known as Cooper’s Ligaments (see Figure 1), play a major role in breast support [22]. Although the true anatomical properties of Cooper’s Ligaments are unknown, their thin fibrous structure is only likely to provide limited support to the breast structure. Furthermore, as other anatomical support to the female breast is limited, the Cooper’s Ligaments can be easily stretched due to repetitive mechanical loading associated with breast bounce, which may in turn lead to breast sag [22]. Therefore, external breast support is required to reduce breast motion associated with participating in physical activity, particularly for women with large breasts.

The main form of external support available to limit breast motion and associated pain during physical activity is a bra. Although bras were initially designed to simply cover the breasts as fashion resulted in lowering of the corset, it soon became evident that bras could serve the additional purpose of providing support to breast tissue [23]. With developments in textiles and fabrics such as nylon, which was invented by DuPont in 1937 [24], designers were able to create new bra designs that were both functional and attractive. However, the introduction of stretch elastic fabric revolutionised the bra
industry by providing a fabric that assisted in supporting the breasts, while allowing designs to become less bulky and more “dainty” [23].

Figure 1: The adult female breast: Frontal view with sagittal section (modified from http://www.melpomene.org/old_site_archive/intheknow/pics/breastanatomy.jpg).

Bra fabric advancements were accompanied by the introduction of a bra sizing system in 1935 that incorporated both cup size (generally indicated by a letter such as A, B, C or greater) and a torso circumference measurement (generally indicated as a dress size measurement such as 10, 12, 14 or greater in Australian sizes or 32, 34, 36 or greater in European sizes) [23, 24]. All bra cup sizes are related to the torso measurement, as bra design is based on breast size in proportion to dress size or the torso circumference measurement. Therefore, a given cup size is not the same for all dress sizes. For example, when using the cross grading method of size allocation, a bra sized 10C is designed to hold the same amount of breast tissue as a 12B bra [25].
By the 1990s bras were often very complex in design (see Figure 2), with a full set of bra patterns consisting of a minimum of five pieces, with most styles having 10 or more pieces [26]. Hardaker and Fozzard [26] suggested that some bra styles included as many as 22 separate pieces, whereas Bressler et al., [24] suggested that current bra designs could consist of up to 43 separate components. The complexity of modern bra design is evident in that each bra style can be produced in approximately 20 different sizes, with some designs produced in as many as 56 different sizes [26].

Figure 2: Design features of an encapsulating sports bra (Page & Steele, 1999 [27]).
Chapter 1

As breast motion and related breast pain are often exacerbated during vigorous physical activity, bras designed specifically for sport have evolved over the last 30 years. In 1977 two American women cut two jock straps apart and stitched them together to form a prototype of a sports bra that would offer more support to them whilst they were exercising compared to a conventional bra [28, 29]. Since this time the literature has advocated that support and protection for the breasts during exercise is of primary importance in preventing breast trauma and discomfort [21] and that sports bras are more effective in limiting breast motion and related breast pain when compared to standard fashion bras or sports crop tops [30]. However, many factors must work in unison to effectively achieve an adequate level of breast support during exercise.

Although substantial literature can be found highlighting the important design features of sports bras in women’s health and sporting magazines [31-34], until recently published research pertaining to sports bra design has been sparse. Most of the research has investigated the effectiveness of sports bras in terms of limiting breast kinematics [35-37] and the associated breast pain [30, 38-42]. Other research has investigated measures of breast strain [43] or the effect of breast support on overall running kinetics [44] or kinematics [36, 38]. Most of the studies have assessed breast motion while participants walked or ran on a treadmill [30, 35-40, 42-44], whilst others have examined breast motion during drop jumping [41] and during a two-step star jump [45]. Based on these studies all researchers suggested that females should seek the additional support of a sports bra during physical activity, with Verscheure [41] and Mason et al. [30] adding that an encapsulating sports bra was more effective that a compression bra in limiting breast motion and associated breast pain.

1 A description of structural differences between encapsulation and compression bras are described in Chapter 2.
Research related to sports bra design has increased exponentially during recent years [46]. Although this research has increased the body of knowledge in this important area, no studies could be found investigating why women do or do not wear sports bras, or what features of current sports bra design may deter or encourage women from wearing sports bras in order to gain sufficient breast support during physical activity. As the purpose of a sports bra is to limit breast motion and allow comfortable participation in physical activity, there would be no benefit in a sports bra that was successful in minimising breast motion but impeded athletic performance or inflicted additional discomfort on the wearer. Therefore, it is important that sports bras are designed to restrict breast motion and related breast pain, while allowing comfortable exercise to be completed. Given the knowledge gap in this field, more research is needed to understand current sports bra usage, factors that affect this usage and possible modifications to sports bra design that could increase the likelihood of sports bras being the choice of breast support for females during physical activity.

**STATEMENT OF THE PROBLEM**

The overall purpose of this thesis was to identify factors that influence breast support choices made by Australian females when they participate in physical activity, and to then systematically investigate factors that may deter females from using sports bras in order to develop recommendations for improving sports bra usage. To achieve this purpose a comprehensive study was initially conducted to investigate the breast support choices made by Australian females when they participate in physical activity (Section A). This section of the thesis analysed consumer “likes and dislikes” of sports bras (Chapter 2), and highlighted design features that may have deterred females from wearing sports bras during physical activity (Chapter 3). As a result of the survey
findings, two subsequent studies were designed to systematically investigate two main problems that were identified with current sports bras (Section B). These problems were the perceived tightness of the sports bra around the wearer’s torso and the effect on breathing ability during physical activity (Chapter 4); and the perceived discomfort problems associated with sports bra shoulder strap designs (Chapter 5). Recommendation pertaining to how we can improve or modify selected features of current sports bra designs in order to limit breast motion and related breast pain so that women can exercise without suffering bra-related discomfort are presented in Chapter 6. A flow chart illustrating the aim of each chapter and how the individual studies systematically contributed to the overall thesis aim is shown in Figure 3.
Thesis Aim:
To identify factors that influence breast support choices made by Australian females when they participate in physical activity, and to then systematically investigate factors that may deter females from using sports bras.

Section A:
What are the breast support choices of Australian women during physical activity (Chapter 2) and what features of sports bras deter their use by women (Chapter 3)?

Section B, Part 1:
Do current sports bra designs impede respiratory function during physical activity (Chapter 4)?

Section B, Part 2:
How do bra strap cushions and strap orientation affect wearer comfort and sports bra efficacy (Chapter 5)?

Thesis Recommendations:
How can we improve or modify current sports bra designs so they can limit breast motion and related breast pain, while not impeding athletic performance or effecting bra efficacy, so that women can exercise without suffering bra-related discomfort (Chapter 6)?

Figure 3: A schematic representation of the structure of the thesis: Sports bra design for active women.
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Section A
Chapter 2

What are the breast support choices of Australian females during physical activity?

This chapter is an amended version of the manuscript: Bowles K-A, Steele JR & Munro B. What are the breast support choices of Australian females during physical activity? *British Journal of Sports Medicine*, 2008; 42(8), 670-673.

**ABSTRACT**

**Objectives:** This study aimed to quantify the breast support wearing and purchasing habits of young women and to assess factors that affect their sports bra usage during physical activity. **Design:** Study results were obtained from a self-administered mail survey, which was posted to participants after gaining their verbal consent via random telephone recruitment. **Participants:** 413 women aged 20 to 35 years were recruited from New South Wales, Australia. **Results:** From the returned (65%) surveys only 41% of respondents currently wore an encapsulating sports bra during physical activity, primarily due to a lack of awareness of the importance of good breast support during physical activity. Bra size was a predictor of sports bra usage, whereby participants with large breasts were more than twice as likely to wear a sports bra as their smaller-breasted counterparts. **Conclusions:** It was concluded that, although encapsulating sports bras have been shown to effectively reduce breast motion and associated exercise-induced breast discomfort, these bras were not the breast support option most commonly chosen by young women during physical activity. It is recommended that all women, irrespective of breast size, be educated on the importance of wearing a well-
fitted and supportive bra during physical activity to decrease excessive strain on breast
tissue structures and related breast discomfort.

**INTRODUCTION**

With growing concerns over increasing obesity in modern society, encouraging
participation in physical activity is of paramount importance. Physical activity not only
lowers obesity levels through changes in metabolic rate, but also positively affects
cardiovascular fitness and overall wellbeing [1]. It has also been suggested that
physical activity can relieve symptoms of depression and anxiety, in turn leading to a
better quality of life through enhanced psychological factors such as self-concept, self-
estee and mood [2]. Physical activity also assists in injury prevention, especially in
women, as oestrogen and weight-bearing exercise work together to increase bone
strength [3].

Anecdotally, it has been suggested that some females refrain from physical
activity due to the pain and/or embarrassment associated with excessive breast motion.
In fact, one report found that up to 70% of female athletes complained of exercise-
induced breast discomfort during exercises involving running and jumping [4].
Excessive breast motion during exercise is a result of the female breast containing
limited anatomical support. The skin covering the breast tissue [5] and the thin bands of
fibrous tissue that divide the breast lobules (Cooper’s ligaments) [6] provide this limited
support, leaving breast tissue relatively free to move over the chest wall if unsupported,
especially during movements of the torso [4]. Even though the medical implications of
excessive breast motion and resultant breast pain are not known, the fact that breast pain
may be present during exercise suggests that some damage might be occurring to the
internal breast structures. This possible breast damage, along with the negative health
implications associated with a lack of physical activity due to exercise-induced breast discomfort, should cause concern to health professionals.

Due to the limited anatomical support within the female breast, external support in the form of a bra is usually recommended to reduce breast motion and associated breast discomfort. Research studies have confirmed that well-designed sports bras, such as encapsulation bras (in which each breast is supported in a separate cup; see Figure 1), are more effective in limiting this motion and associated breast discomfort than standard fashion bras or crop tops, which attempt to reduce breast motion by compressing the breasts against the chest wall [7-11]. Despite this research, it is not known whether women within the general community are aware of the importance of adequate breast support during exercise. In addition, no literature was found assessing sports bra usage or associated bra-related behaviours in a community-based female population. Therefore, the aim of this study was to quantify the breast support-wearing and purchasing habits of young women, focusing on breast support choices for physical activity. This included quantifying sports bra usage and other behaviours that may affect sports bra purchasing, such as age, bra size, participation in physical activity and breast pain occurrence.
Figure 1: An encapsulating sports bra in which each breast is supported by a separate cup.

METHODS

Survey development

Due to the sensitive nature of assessing underwear preferences, and with the aim of gaining information from a broad geographic area, a self-administered mail survey was used to gather data [12-14]. The survey was developed with assistance from an epidemiologist and bra industry representatives, and content validity was established through focus groups composed of women in the target population, described below. The 31-question survey (see Appendix A), including both closed and open-ended items, sought information on each respondent’s demographics, bra purchasing habits and fitting history, occurrence of breast pain, physical activity participation, breast support worn during physical activity, sports bra use and factors affecting why the respondents did or did not wear a sports bra.
Test-retest analysis, completed on all non-time related questions, deemed the survey was reliable \((r = 0.72, \ p \leq 0.05)\) [12]. Full approval of the content and conduct of the survey was received from the University of Wollongong Human Research Ethics Committee (HE99/110) prior to implementation of the survey.

**Survey implementation**

Women aged 20 to 35 years who resided in New South Wales (NSW), Australia, were targeted as potential study respondents as they were deemed a good representative sample of the Australian female population due to the diverse socioeconomic, cultural and geographic regions throughout NSW.

In order to gain weighted information across the broad geographical area of NSW, a stratified sampling technique was performed, with subgroups formed on the basis of Telstra White Pages telephone directory zones (Sensis, Australia) and regions of the Australian Bureau of Statistics’ estimated resident population [12-15] census. Using Cochran’s Formula for Sampling Proportions [16] it was determined that 100 respondents were required to gain an adequate sample size with a standard error of 0.05. However, this number was increased (see Results section) to ensure sufficient subjects in each subgroup were sampled, within the time and financial constraints of the study.

To identify potential respondents who fulfilled the subject selection criteria, to obtain verbal consent to send a survey package, and to promote a higher survey return rate, contact was made via telephone, using a set script (see Appendix B) to ensure uniformity in response to each potential subject, before distributing the surveys [14, 17, 18]. Prospective telephone numbers were generated using a random numbers generation with a uniform distribution (Microsoft Excel, Microsoft Corporation, USA).
Data were generated for page number, row number and column number for each White Pages telephone directory.

If a prospective respondent provided verbal consent to participate in the survey, their postal address details were confirmed and a questionnaire, written consent form, letter of explanation and stamped self-addressed envelope for survey return were mailed to the address. A non-monetary incentive of entry into a random draw to win $200 worth of lingerie was offered to the respondents when the survey was returned to the researchers to increase response rate [13, 14, 17-19]. The brand of lingerie was not specified in order to reduce any brand bias.

A total of 4413 telephone calls were made over 12 months by a team of seven trained research assistants. From these calls, 480 potential respondents were identified and 413 of these respondents volunteered to participate in the study and were mailed a survey package. A follow-up reminder letter and complete survey package were mailed to each respondent who had not returned the survey after 4 weeks. No further follow-up was completed due to restrictions imposed by the Human Research Ethics Committee.

Of the 413 survey packages mailed to consenting respondents, 267 questionnaires were completed and returned by respondents who fulfilled the subject selection criteria (65% response rate). This response rate was considered high for a mail survey as traditional mail surveys typically have an average response rate of below 20% [19]. A further seven questionnaires returned for analysis were completed by respondents outside the set age range and were therefore excluded from further analysis. The average age of survey respondents was 27.2 (SD 4.9) years with 101 (38%) respondents aged 20-24 years, 67 (25%) respondents aged 25-29 years and 99 (37%) respondents aged 30 plus years. Age groups were set in accordance with Australian Bureau of Statistics age groups for explaining population demographics [15].
Survey analysis

Bivariate analysis was completed on each survey component, investigating relationships between bra size and age using cross tabulations and $\chi^2$ analysis (SPSS 12.0.1, SPSS Inc., USA). All data were grouped into categories to ensure assumptions of the $\chi^2$ analysis (including a minimum expected frequency above five) were met [20]. Physical activities were coded according to the amount of vertical breast motion that might occur during that activity using the Berlei grading system [21]. Activities that typically result in the least to greatest amount of vertical breast motion were coded as Factor 1 to Factor 3 activities, respectively.

To determine which variables might significantly predict sports bra usage, multivariate analysis via a logistic regression was performed. A forced-entry model for demographic predictors of sports bra usage was developed reporting odds ratios and 95% confidence intervals. In all analyses, statistical outcomes were deemed significant at an alpha level of $p \leq 0.05$.

RESULTS

Bra size

Respondents reported 26 bra sizes, ranging from metric size 10A to 18H/20DD (imperial size, 32A to 40H/42DD). The most common size reported by respondents was 12B (imperial size, 34B; 23%). When the bra sizes were grouped into small (A and B cup) and large ($\geq$ C cup)-breasted categories, [7, 8, 22] 114 (43%) respondents were classified as small-breasted and 150 (56%) respondents were classified as large-breasted, with three respondents not reporting a bra size (see Table 1). Age and bra size were significantly related, with respondents aged 25-29 years less likely to be small-
breasted than would be expected ($\chi^2 = 6.55; p = 0.04$; see Table 1). However, it should be noted that bra sizes were self-reported and, as 70-100% of females reportedly wear the incorrect size bra [23], the bra size data should be interpreted with caution.

Table 1: Number of respondents according to age group and bra size categories ($n = 267$).

<table>
<thead>
<tr>
<th>Age group</th>
<th>Small-breasted (%)</th>
<th>Large-breasted (%)</th>
<th>Size not provided (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-24 yr</td>
<td>47 (18)</td>
<td>53 (20)</td>
<td>1 (0)</td>
<td>101 (38)</td>
</tr>
<tr>
<td>25-29 yr</td>
<td>20 (7)</td>
<td>47 (18)</td>
<td>0 (0)</td>
<td>67 (25)</td>
</tr>
<tr>
<td>30-35 yr</td>
<td>47 (18)</td>
<td>50 (19)</td>
<td>2 (1)</td>
<td>99 (37)</td>
</tr>
<tr>
<td>Total</td>
<td>114 (43)</td>
<td>150 (56)</td>
<td>3 (1)</td>
<td>267 (100)</td>
</tr>
</tbody>
</table>

Sports bra usage

Although 71% of respondents indicated that they had worn an encapsulating sports bra at some time, only 41% of respondents indicated that they currently wore an encapsulating sports bra during physical activity. Age group ($\chi^2 = 10.58; p \leq 0.01$) and bra size ($\chi^2 = 13.38; p \leq 0.01$) were both significantly related to respondents ever wearing a sports bra during physical activity, with only bra size significantly related to current sports bra use ($\chi^2 = 11.49; p \leq 0.01$). That is, respondents aged 25-29 years had worn a sports bra at some time during physical activity more frequently than would be expected, as did the respondents with large breasts, and a greater number of respondents with large breasts currently wore a sports bra than expected. It was interesting to note that bra size was significantly related to the correct identification of a sports bra ($\chi^2 = 13.33; p \leq 0.01$), as women with large breasts more readily correctly identified the
encapsulating sports bra as a sports bra (see Figure 1) than their small-breasted counterparts.

Perhaps the most pertinent question in the survey asked why respondents did not currently wear an encapsulating sports bra during physical activity. The most common responses to this question included ‘‘I do not feel I need to’’ (27%) and ‘‘I have not considered wearing one’’ (15%).

**Breast pain**

One hundred and seventy-one (64%) respondents indicated that they suffered from breast pain at some time, with 45% of these respondents indicating that they believed this pain was due to menstruation. Bra size and age were not significantly related to breast pain (bra size: $\chi^2 = 1.11; p = 0.29$, age: $\chi^2 = 0.28; p = 0.87$) or the believed cause of the breast pain (bra size: $\chi^2 = 1.67; p = 0.64$, age: $\chi^2 = 12.02; p = 0.06$).

**Physical activity**

Most respondents (41%) reported their activity level as ‘‘moderately active’’. However, there were no significant relationships between breast size ($\chi^2 = 1.59; p = 0.45$) or age ($\chi^2 = 3.86; p = 0.43$) and the reported level of physical activity. In addition, despite 60% of respondents indicating they participated in activities typically associated with high levels of vertical breast motion (Factor 3 activities), bra size ($\chi^2 = 0.13; p = 0.72$) was not significantly related to involvement in Factor 3 activities. However, a significant relationship was found between age group and involvement in Factor 3 activities ($\chi^2 = 21.44; p \leq 0.01$), whereby the older women (30-35 years) did not report participating in activities typically associated with large amounts of vertical breast motion.
displacement (43%) as much as their younger counterparts (20-24 years; 76%). When asked what they mostly used for breast support during the reported physical activities, 88 respondents (34%) indicated that they wore a fashion bra, whereas 84 respondents (32%) reported wearing a sports bra. Bra size and age were not significantly related to breast support choices during the physical activities ($\chi^2 = 6.43; p = 0.09; \chi^2 = 7.32; p = 0.29$, respectively), suggesting that, overall, women were slightly more likely to wear a fashion bra during physical activity than the more research-recommended sports bra, regardless of their age or bra size.

**Sports bra features**

Although fit (93%), stopping breast motion (71%) and the presence of underwire (45%) were current sports bra features classified by the respondents most frequently as ‘very important’, straps slipping off the shoulder (34%) and straps cutting into the shoulder (34%) were the main sports bra features respondents ‘extremely disliked’. Age was not significantly related to the importance or disliking of any sports bra feature. However, there was a significant relationship between bra size and several sports bra features including fit ($\chi^2 = 5.05; p = 0.03$), presence of underwire ($\chi^2 = 10.52; p \leq 0.01$) and stopping breast motion ($\chi^2 = 10.92; p \leq 0.01$). That is, women with large breasts reported these three features as very important more readily than their small-breasted counterparts. With regard to disliked features, bra size was significantly related to the sports bra ‘creeping up’ ($\chi^2 = 6.70; p = 0.04$), with small-breasted subjects reporting this as a disliked feature more frequently than their large-breasted counterparts.
DISCUSSION

Previous research has found encapsulating sports bras to be more effective in limiting breast motion and associated breast pain than fashion bras or crop tops [8]. However, fewer than half of the present respondents indicated they currently wore an encapsulating sports bra during physical activity, despite the fact that more than half of the respondents were classified as large-breasted (see Table 1). Age group and bra size were both significantly related to respondents ever wearing a sports bra during physical activity, whereby respondents aged 25-29 years had worn a sports bra at some time during physical activity more frequently than would be expected, as had respondents with large breasts. These results are consistent with the findings that respondents aged 25-29 years were classified as large-breasted more frequently than would be expected. Interestingly, only bra size was significantly related to current sports bra use. Although it is possible that respondents with large breasts are seeking good breast support during physical activity, women with small breasts have been shown to experience 8 cm of vertical nipple displacement during running when unsupported [7]. Furthermore, the finding that 35% of the respondents with large breasts who did not wear a sports bra during physical activity indicated that they “had not considered wearing one” suggests that not all young women are aware of the importance of adequate external breast support during physical activity. This result reinforces the need to educate all women on the importance of good breast support during physical activity. In designing and implementing these education programmes, factors such as the age group and bra size of the target audience should be considered.

Apart from educating women on the benefits of wearing good breast support during physical activity, education should also focus on features of a good supportive sports bra. There are currently no guidelines or standards that a bra must meet to be
Chapter 2

classified as a sports bra. In fact, less supportive crop tops [7] are frequently marketed as sports bras, with 20% of respondents in the present study reporting that they believed a crop top was a sports bra. It is therefore recommended that international standards be developed so that women can more easily identify the bras that will provide adequate support during physical activity.

Although the present results suggest that breast pain is experienced by women regardless of bra size or age, despite 60% of respondents indicating they participated in Factor 3 activities, only nine respondents (5% of those who did suffer from breast pain) indicated that their perceived breast pain was due to excessive breast motion. This finding is contradictory to previous research where up to 70% of women who participated in running and jumping activities reported exercise-induced breast pain [4].

The fact that most respondents in the present study reported being involved only in moderate-level activity, with older women (30-35 years) participating less in activities typically associated with large amounts of vertical breast displacement (Factor 3 activities) than their younger counterparts, may be a possible explanation for the discrepancy between the two studies. Interestingly, the fact that bra size was not significantly related to either the types of activities performed or the level of physical activity was a positive finding, as these results negate the anecdotal suggestion that breast size can impede participation in physical activity. However, the finding that 60% of respondents were participating in Factor 3 activities although not wearing a sports bra is alarming considering the negative consequences potentially associated with poor breast support during physical activity.

This study also highlighted the different requirements women have from a sports bra depending on their breast size. That is, women with large breasts had a preference
for underwire in their sports bra, and more readily recognised the importance of the bra’s ability to reduce breast motion.

**CONCLUSION**

The results of this study suggest that encapsulating sports bras are not the most common choice of breast support during physical activity for young women. Although respondents with large breasts were more likely to wear a sports bra during physical activity than their small-breasted counterparts, it appears that scientific results highlighting the greater ability of encapsulating sports bras to reduce excessive breast motion during physical activity have not reached this population. Interestingly, the reasons respondents did not wear a sports bra were not size-specific; neither was the occurrence of breast pain nor the types of physical activities women were involved in. However, as the medical implications of poor breast support during physical activity are not well-documented and as large amounts of breast motion can occur in women both with large and with small breasts, these findings reinforce the need to educate all women, irrespective of breast size, on the importance of wearing a well-fitted and supportive bra during physical activity. In designing and implementing these education programmes, factors such as the age and bra size must be taken into consideration, as these factors affect the bra usage and purchasing habits of young women.
REFERENCES


8. Verscheure SK. *How effective are sports bras designs in attenuating forces during jumping*. 1999; Unpublished Masters of Science, University of Oregon.


Chapter 3

Features of sports bras that deter their use by Australian women.

This chapter is an amended version of the manuscript: Bowles K-A, Steele JR & Munro B. Features of sports bras that deter their use by Australian women. Journal of Science and Medicine in Sport, 2012; 15(3), 195-200.

ABSTRACT

Objectives: This study aimed to identify features of commercially available sports bras that deter women from wearing them while participating in physical activity. Design: Study results were obtained from a self-administered mail survey, which was posted to participants after gaining their verbal consent via random telephone recruitment. Methods: Four hundred and thirteen women aged 20 to 35 years were recruited from New South Wales, Australia, with 267 (65%) surveys returned. Results: It was found that the shoulder straps slipping off or cutting into the shoulder were the two most disliked features of current sports brassieres, with 23% of respondents also indicating that the shoulder straps were the first brassiere feature to fail. Respondents also indicated that the perceived tightness of the sports bra around the chest was a deterrent for their use. Conclusions: Further research is required to investigate sports bra shoulder strap designs and the perceived tightness around the chest to improve wearer comfort without negatively affecting the ability of a sports bra to reduce breast motion and/or associated breast pain during participation in physical activity.
INTRODUCTION

As breast motion and associated breast pain are often exacerbated during vigorous exercise, bras designed specifically for sport have evolved since the late 1970’s. At this time, two American women cut jock straps apart and stitched them together to form a sports bra prototype that would offer more breast support whilst they were exercising compared to their usual bras [1]. Advancements in design and textile technology over the past four decades have seen the development of materials such as Lycra®, Elastane and Cool Max®, which are now readily incorporated into the much more complex designs of current sports bras. As a result of these more sophisticated materials, support and protection of the breasts during exercise is of primary concern when designing sports bras in order to prevent breast trauma, irreversible damage to breast tissue and breast discomfort [2]. In fact, biomechanical studies that have investigated the effects of bra design features on breast motion have consistently shown that well-designed sports bras are effective in limiting excessive breast motion and related breast pain [3-9]. More specifically, sports bras that encapsulate each breast individually using moulded cups (encapsulating sports bras) have been found to be more effective in limiting breast motion and related breast pain compared to standard fashion bras or sports crop tops [3], which compress the breasts against the torso (compression sports bras). In addition, Hindle [2] and Stamford [10] recommended that women with larger breasts (sizes C+) required more support than their smaller-breasted counterparts. Apart from reducing exercise-induced breast discomfort, appropriate breast support also allows women with larger breasts to exercise without the embarrassment of excessive breast bounce, which can lead to these women refusing to participate in physical activity [11].
Despite scientific evidence confirming the benefits of wearing appropriate breast support, our previous research has indicated that less than half the survey respondents (267 women aged 20 to 35 years) wore an encapsulating sports bra during physical activity [12]. In addition, although 71% of respondents had worn an encapsulating sports bra at some time, only 41% currently wore an encapsulating sports bra during physical activity. This finding suggests consumer dissatisfaction with current sports bra designs. Although we speculated that education might play a large role in improving sports bra usage, the results also implied that consumers believe that current sports bra designs need to be improved if women are to wear them more frequently while they are exercising.

Despite an increasing amount of literature highlighting the important aspects of sports bra designs for consumers [10, 13-15], only limited attention has been given in the scientific literature to the success or failure of various sports bra design features in reducing breast motion [3-5, 16]. Berger-Dumound [17] reported on an evaluation study, where the bra that was the most effective in terms of limiting breast motion was not rated highly in comfort, and that the most comfortable sports bras were among the worst performers in controlling breast motion. Other reports commented that, although breast motion is limited most effectively when a bra firmly holds the breast tissue close to the body, there is a need for sufficient elastic in the horizontal plane to allow the chest to expand during respiration [13].

The use of an encapsulating sports bra during physical activity is recommended in the scientific literature to reduce breast motion and associated breast discomfort [3-9], with sports medicine clinicians, such as physiotherapists, encouraged to assess and recommend sports bra usage in their female patients [18]. However, our previous research has suggested that an encapsulating sports bra was not the most common
choice for breast support during physical activity [12]. Therefore, it is important to further investigate factors that deter women from wearing sports bras, particularly those factors related to sports bra design, so that sports bras can be modified in a manner that will increase their usage among women. Our previous research also indicated that straps slipping off the shoulder (34%) and straps cutting into the shoulder (34%) were the main features of sports bras that women "extremely disliked". However, no discussion of bra strap design nor what other bra design features might deter women from wearing a sports bra when they participate in physical activity was offered. Therefore, the aim of the present study was to identify and discuss features of commercially available sports bras that deter women from wearing them while participating in physical activity.

METHODS
A custom-designed 31-question, self-administered mail survey (see Appendix A) was used to comprehensively assess aspects of sports bra usage by women living in the community. A detailed description of the development and implementation of the survey has been previously described elsewhere [12], with the survey deemed to demonstrate content validity and good test-retest reliability ($r = 0.72$). In brief, 4413 telephone calls were made over 12 months, with 480 potential respondents (women aged 20 to 35 years who resided in New South Wales (NSW), Australia, and had their telephone number listed in the Telstra White Pages telephone directory (Sensis, Australia)) identified. A total 413 of these respondents volunteered to participate in the study. Initial survey questions focused on demographics such as age and bra size, to allow any significant differences between these demographic factors to be established. Respondents were then asked to answer questions related to their bra wearing and
purchasing habits, including questions to ascertain their level of satisfaction with specific bra design features. Respondents who indicated that they wore an encapsulating sports bra (either around the time of the survey implementation, referred to as currently; or when completing their normal physical activities) were asked to assess what features in current sports bras they disliked and what feature of the sports bra failed first. If respondents indicated that they did not currently wear an encapsulating sports bra during physical activity (n = 158), they were asked what feature(s) of the sports bra deterred their use.

Written questionnaire data were obtained from 267 respondents (65% response rate) with the average age of the respondents being 27.2 years (SD 4.9 years) and the most common self-reported bra size being a 12B (imperial size ~ 34B; 23%). One hundred and eight respondents indicated that they currently wore an encapsulating sports bra (SB), 158 respondents indicated that they did not currently wear an encapsulating sports bra (NSB), with one non-response to this question (267 = 108 + 158 + 1). Twenty respondents who indicated they did not currently wear an encapsulating sports bra but did when completing their usual physical activity, participated in sports that were not in season at the time of survey completion. To allow for the seasonal effect of the study, these 20 respondents were classified as sports bra wearers (SB) for the purpose of data analysis, with their responses to questions as non sports bra wearers removed from the data set (266 = 128 (SB) + 138 (NSB)).

Initial descriptive statistics were recorded from the returned surveys to allow deterrent factors to be identified. Secondary descriptive statistics in the form of bi-variate analyses were then completed on each component of the survey to investigate relationships between design factors and bra size (smaller [A-B cup] and larger [C cup+] bra sizes) and/or age (20-25 years; 26-30 years; and 31-35 years) using cross
tabulations and Chi-square analysis (SPSS 12.0.1, SPSS Inc., USA) for responses to 11 of the survey questions. Full approval of the content and conduct of the survey was obtained from the University of Wollongong Human Research Ethics Committee (HE 99/110) prior to survey implementation and all research participants provided written informed consent.

RESULTS

The most disliked features in current sports bra designs, reported by respondents who wore a sports bra are listed in Table 1. The bra shoulder straps cutting in, the shoulder straps slipping off and/or the fasteners digging in were the most likely features to be extremely disliked. There was no significant difference between the respondents with larger or smaller breasts in regard to either their dislike of the shoulder straps cutting in ($\chi^2 = 3.08; p = 0.21$), shoulder straps slipping off ($\chi^2 = 4.19; p = 0.12$) or the fasteners digging in ($\chi^2 = 2.83; p = 0.24$). In addition, there was no significant relationship between respondent age and dislike of the shoulder straps cutting in ($\chi^2 = 6.83; p = 0.15$), the shoulder straps slipping off ($\chi^2 = 1.39; p = 0.85$) or the fasteners digging in ($\chi^2 = 5.34; p = 0.25$).
Table 1: Ratings by the respondents of dislike for 11 sports bra features (n = 106; n = 22 non-responses).

<table>
<thead>
<tr>
<th>Bra Feature</th>
<th>Extremely disliked</th>
<th>Slightly disliked</th>
<th>Not an issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straps Cutting In</td>
<td>34%</td>
<td>32%</td>
<td>33%</td>
</tr>
<tr>
<td>Straps Slipping</td>
<td>34%</td>
<td>24%</td>
<td>43%</td>
</tr>
<tr>
<td>Fasteners Digging In</td>
<td>28%</td>
<td>22%</td>
<td>50%</td>
</tr>
<tr>
<td>Creeping Up</td>
<td>21%</td>
<td>23%</td>
<td>56%</td>
</tr>
<tr>
<td>Bra Cost</td>
<td>17%</td>
<td>44%</td>
<td>38%</td>
</tr>
<tr>
<td>Stitching Rubbing</td>
<td>17%</td>
<td>25%</td>
<td>58%</td>
</tr>
<tr>
<td>The Look</td>
<td>13%</td>
<td>27%</td>
<td>59%</td>
</tr>
<tr>
<td>Neckline</td>
<td>4%</td>
<td>29%</td>
<td>67%</td>
</tr>
<tr>
<td>Fabric</td>
<td>4%</td>
<td>26%</td>
<td>70%</td>
</tr>
<tr>
<td>Colour</td>
<td>3%</td>
<td>15%</td>
<td>83%</td>
</tr>
<tr>
<td>Brand Name</td>
<td>3%</td>
<td>3%</td>
<td>94%</td>
</tr>
</tbody>
</table>

The bra components that were most frequently reported as the first to fail by the respondents who wore a sports bra are illustrated in Figure 1. The component reported to fail first most frequently was the bra shoulder strap. There was no significant relationship between what bra feature respondents reported as failing first in their sports bras and age ($\chi^2 = 3.76; p = 0.44$) or bra size ($\chi^2 = 0.58; p = 0.75$).
For those respondents who did not wear a sports bra, 7% of respondents reported that the perceived tightness around the chest of current sports bras was the greatest deterrent to wearing a sports bra with another 7% reporting a range of design and sizing issues, including underwire concerns, were the greatest deterrent (see Figure 2). Six percent of respondents reported that the look of sports bras was the greatest deterrent and 3% reported that the cost was the greatest deterrent. Twenty-three percent of those respondents who did not wear a sports bra reported that it was a combination of issues that acted as a deterrent to the use a sports bra, with all listed deterrents contributing to this figure. After assessing each deterrent’s contribution to the combined data, it was calculated that 15% of the respondents indicated that the look of current sports bras was a deterrent to their use, 9% reported that the perceived tightness of current sports bras around the chest was a deterrent to their use, and 8% reported that the cost was a deterrent to sports bra use. The reasons deterring women from wearing a sports bra were not significantly related to the respondent’s age or bra size ($\chi^2 = 5.33; p = 0.26$ and $\chi^2 = 3.29; p = 0.19$; respectively).
When questioned on current bra purchasing habits, respondents (n = 267) indicated that they spent significantly more money on fashion bras than sports bras ($\chi^2 = 20.81; p < 0.01$). The respondents, however, indicated that they would be prepared to spend significantly more money on an “effective” sports bra compared to those sports bras currently available ($\chi^2 = 39.53; p < 0.01$). No significant difference was found between purchasing habits for a fashion bra compared to an effective sports bra ($\chi^2 = 4.70; p = 0.20$).
DISCUSSION

Our previous research has revealed that a large percentage of women who had sought the additional support of a sports bra, did not currently wear an encapsulating sports bra during physical activity [12], suggesting dissatisfaction with current sports bra designs. Although a common reason for not wearing a sports bra during physical activity may be related to inadequate education about the need for breast support, the present study has identified several cost and design features of sports bras that deter women from wearing them while participating in physical activity. These deterrent features are discussed below.

The results of the present study highlighted that, although survey respondents currently spent more money on fashion bras than sports bras, they would be prepared to spend significantly more money on an effective sports bra than those currently available. This finding further supports the notion of consumer dissatisfaction with current sports bra designs and highlights the consumer belief that improvements could be made to current sports bra designs. The results also highlight the need to further investigate the disliked features of current sports bra designs in order to not only improve their use by active women, but also to decrease the risk of current sports bra users rejecting them as a source of breast support during physical activity.

Shoulder straps, particularly straps cutting into the shoulders or slipping off the shoulder, were found to be the most disliked feature in current sports bras and were the first structural feature of the bra to fail, regardless of respondent age or bra size. These results are of extreme importance to bra designers and manufacturers, as this dislike or mechanical failure in the current sports bra designs may act as a future deterrent for their use. Although some literature states that fabric in the shoulder strap of a sports bra should contain minimal elastic in the vertical plane to limit vertical breast movement
Cummins [19] suggested that bra shoulder straps should never dig into the shoulder, as their role is to hold the bra in place, not to support the breasts. De Silva [20] suggested that if tight and narrow bra shoulder straps support heavy breasts, the straps will cut into the soft tissue around the shoulders. This, in turn, exerts downward pressure on the middle and lateral aspects of the clavicle, pressing the clavicle against the first rib with a resultant shearing of the neurovascular bundle and a narrowing of the costoclavicular passage by a forward shift of the scapula [20]. In addition to developing deep furrows or grooves in the soft tissue where the bra strap lies on the shoulders, the downward pressure of the bra strap can result in paraesthesia and fatigue in the upper limbs and occasional complaints of puffy blue hands [20] and, in more severe cases, ulnar nerve dysfunction [21].

To reduce shoulder strap pressure, De Silva [20] suggested that women should wear either a strapless bra or a bra with broad shoulder straps. He also suggested possibly threading the shoulder straps through a pad, which could distribute forces applied to the shoulders over a greater area. No research could be found quantifying the pressures generated on the shoulders by bra straps, nor was any published literature identified assessing the effect of wider bra shoulder straps on this resultant pressure.

Although no published literature was identified that has assessed the medical implications of bra straps slipping off the shoulders of the wearer, various shoulder strap configurations are now available in encapsulating sports bras (e.g. vertical, cross-over, T-bar and racer-back), and these strap variations should provide options to prevent the shoulder straps from slipping off. The fact that the shoulder strap slipping off was disliked by greater than 50% of those respondents who wore a sports bra should be a factor considered by bra manufacturers and those promoting their use. Furthermore, no published literature was identified comparing the effects of sports bra shoulder strap
configurations on a sports bra’s efficacy, and all of the referenced literature investigating the effects of encapsulating bras on breast motion has used bras with only one bra shoulder strap configuration (i.e. vertical strap alignment) [3-9]. This paucity of scientific literature pertaining to strap design confirms the need for future research to investigate the effects of variations in shoulder strap configuration and design on the comfort and performance of sports bras.

Although the look of current sports bras was highlighted as a deterrent to their use by respondents who did not wear a sports bra, 9% of these respondents also indicated that they perceived current sports bras as being too tight around their chest. This finding is lower than we anticipated, after anecdotal reports from focus groups and bra industry representatives suggested that the perceived tightness around the chest could deter women from wearing sports bras during physical activity. Although sports bras are required to fit firmly to the torso in order to hold the breast tissue close to the body, there is a need for sufficient elastic material in the horizontal plane to allow the chest to expand whilst breathing [13]. Research has shown that tightness around the chest wall can be problematic to exercise performance whereby applying external chest wall strapping can significantly decrease resting lung volumes, leading to significant decreases in exercise performance and, in turn, significantly more shallow and rapid breathing patterns during exercise [22]. Caro et al. [23] and McIlroy et al. [24] also suggested that chest strapping decreased lung volumes such as functional residual capacity, with Caro et al. [23] and Zechman and Wiley [25] reporting significant reductions in the expiratory reserve volume in subjects with artificial chest motion restriction. The authors suggested that these changes in lung volumes might be due to closure of terminal lung units, or alveoli, as a result of the chest restriction [25]. The
paucity of literature in regards to the effect of bra tightness around the chest on exercise performance does warrant further investigation.

CONCLUSION

As wearing a well-fitted encapsulating sports bra during exercise has been shown to be beneficial to reducing breast motion and associated exercise-induced breast discomfort, it is vital that we understand the features that deter their use when women participate in physical activity and that we transfer this knowledge to the designers and manufacturers of these products. One of the main bra design features highlighted by respondents as a deterrent to wearing sports bra in this study was the perception that sports bras are too tight around the chest of the wearer. This finding does warrant further investigation to ensure that the positive benefits of wearing a sports bra for physical activity, such as decreased breast motion and associated breast pain, are not negated by a decrease in exercise performance. In addition, the potential negative health consequences associated with excessive pressures caused by poor shoulder strap design, combined with the rating of shoulder straps as the most disliked features of current sports bras, highlights the need for further research to investigate the effects of bra shoulder strap design on the overall efficacy of sports bras and the resultant comfort to the wearer.
REFERENCES


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8. Shivitz NL. *Adaptation of vertical ground reaction force due to changes in breast support in running*. 2001; Unpublished Masters, Oregon State University.


Section B
Chapter 4

Do current sports bra designs impede respiratory function?

This chapter is an amended version of the manuscript: Bowles K-A, Steele JR & Chaunchaiyakul R. Do current sports brassiere designs impede respiratory function? Medicine and Science in Sports and Exercise, 2005; 37(9), 1633-1640.

ABSTRACT

Purpose: Although sports bras are more effective in limiting breast motion and related breast pain when compared with standard fashion bras, some females do not wear sports bras during physical activity, as they perceive them to be too tight around the torso, possibly impeding their performance during physical activity. The purpose of this study was to determine whether breast hypertrophy, breast momentum, and/or wearing a sports bra impeded respiratory function at rest and during physical activity. Methods: Twenty-two active women completed standard resting spirometry manoeuvres while not wearing a bra. All subjects then completed maximal cycle ergometer testing in two breast support conditions (sports bra and no bra (NB)), followed by submaximal treadmill exercise tests under three breast support conditions (sports bra, no bra and fashion bra) while standard spirometry, bra pressure and comfort were measured. Results: The sports bra imparted significantly more pressure on smaller breasted females’ torsos when compared with the fashion bra (0.861 ± 0.247 and 0.672 ± 0.254 N·cm⁻², respectively), although this increased pressure did not appear to significantly affect measured lung volumes or bra comfort scores. Bra size affected maximal exercise ability (relative VO₂peak: smaller breasted NB: 49.84 ± 6.15 mL·kg⁻¹·min⁻¹; larger breasted NB: 40.76 ± 4.47 mL·kg⁻¹·min⁻¹) as well as some temporal measures of
resting and submaximal respiration. However, no significant difference was found between the no bra and bra conditions in regards to measured lung volumes. **Conclusions:** As no significant restriction to exercise performance or respiratory mechanics was found when subjects wore sports bras, it was concluded that active females should wear a sports bra during physical activity to reduce breast motion and related breast pain.

**INTRODUCTION**

Sports bras have been shown to be more effective in limiting breast motion and related breast pain compared with other forms of external breast support [1]. However, anecdotal evidence suggests that females are often deterred from wearing sports bras during physical activity, as they perceive sports bras to be too tight around their chest and, in turn, may impede their athletic performance. Although sports bras are typically restrictive around the torso in an attempt to limit breast motion and related breast pain [2], the effects of this restrictiveness on respiratory function and resultant physical performance has not been examined.

Although no research pertaining to the effects of bra design on respiratory function was located in the literature, several studies have investigated the effects of strapping the chest region on respiratory function [3-5]. This previous research has provided evidence that strapping the chest wall can impede respiratory function by reducing functional residual capacity (FRC) and limiting inspiratory chest wall motion [3]. Although the magnitude of the reported reduction in lung volume varies among studies, it is thought that the reduction in FRC may be primarily attributed to reductions in the expiratory reserve volume (ERV) [3], with several researchers suggesting poor ventilation in some regions of the lung as a result of chest strapping [3, 4]. O’Donnell
et al. [5] have also reported finding significant decreases in resting lung volumes and exercise performance and significantly more shallow and rapid breathing patterns during exercise when chest strapping was applied to their subjects compared with exercise with no chest strapping.

In addition to the paucity of literature relating to bra design effects on respiratory function, no research was found investigating the effects of breast hypertrophy on respiratory function during physical activity or at rest. That is, it is not known whether momentum developed by female breasts during physical activity affects chest wall motion, which, in turn, impedes respiratory function, or whether the presence of large amounts of breast tissue imitates those results seen in the overweight and obese populations, with additional mass placed on the external chest. Obesity is associated with reduced lung volumes, especially reductions in ERV [6], vital capacity (VC) and forced expiratory volumes in 1 s (FEV\textsubscript{1}) [20]. Babb et al. [6] suggested that the smaller ERV seen in obese individuals was due to a reduction in either the end-expiratory lung volume (EELV) or the FRC, although no such research has investigated whether similar reductions in lung volumes are observed in larger breasted women. Therefore, the purpose of this study was to determine whether the presence of breast hypertrophy, or the breast momentum developed by larger breasted women and/or wearing a sports bra impeded respiratory function at rest or during physical activity. Based on the reviewed literature it was hypothesised that an increase in the external pressure applied by a sports bra would be coupled with a decrease in respiratory function during physical activity in all subjects, relative to less restrictive breast support conditions. In addition, it was hypothesised that larger breasted subjects would display reduced respiratory function when compared with the smaller breasted subjects, both at rest and during physical activity.
METHODS

Subjects

After being provided a subject information package and being professionally fitted for a bra by the Chief Investigator (K-AB; see Appendix C), 22 healthy active female volunteers (mean age = 25.14 ± 4.82 yr; height = 166.5 ± 4.5 cm; mass = 65.11 ± 9.2 kg) were recruited for this study from staff and students at the University of Wollongong. The women were allocated to one of two subject groups (11 per group) based on their bra size: (i) smaller breasted women (A cup bra) or (ii) larger breasted women (≥C cup bra). Subjects presenting with lower limb musculoskeletal disorders or cardiorespiratory problems, breast surgery/implants, or previous or current pregnancies were excluded from participating in the study. After providing written informed consent, subjects completed a pulmonary function and physical activity questionnaire (see Appendix D) [7]. All subjects then attended the laboratory on four separate occasions, each visit scheduled within 2 weeks after the onset of their menses, at the same time each day, and with a minimum of 48 hours between testing sessions (see Table 1). At the commencement of the initial visit, each subject’s height and weight were recorded in triplicate to later calculate body mass index (BMI) and weight adjusted \( \dot{V}O_2\text{peak} \).
Table 1: Subject testing schedule during the four laboratory testing sessions.

<table>
<thead>
<tr>
<th>Testing protocol</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resting spirometry</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Maximal exercise testing (cycle ergometer)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>Submaximal exercise testing (treadmill)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
</tbody>
</table>

Day 1 was used for familiarisation only. All maximal and submaximal trial conditions were randomly allocated to prevent any fatigue, order, or learning effects.

Bras

Two bra styles were tested in this experiment, a fashion bra (Berlei Touched; made from Meryl nylon and white Elastane®; A cup with no underwire; C+ cup with underwire) and a sports bra (Berlei Ultrasport; made from white nylon, cotton, polyester and Lycra®; A cup with no underwire; C+ cup with underwire).

All bras, regardless of size or style, were encapsulating in design with structured bra cups. The subjects were fitted for the fashion bra and then provided with a sports bra of the same size. The chief investigator (K-AB) assisted each subject to fit their bras for each trial, attaching each bra at the middle hook and eye on the rear fastener of the bra and adjusting the shoulder straps for individual subject comfort. Each subject wore new bras during their test sessions to ensure that there was no adverse effects of either wear or washing on the bras.

Resting spirometry protocol

To determine whether bra size affected resting respiratory function, spirometry measures were collected (50 Hz; DAS 1602, Metra-Byte; Keithley Data Acquisition, Taunton, MA) for each subject while she stood on a treadmill, wearing a nose clip and
breathing into a Hans Rudolph low-resistance heated pneumotachograph (model 8430) via a mouthpiece connected to a spirometry filter. The pneumotachograph was connected to a differential pressure transducer (Validyne DP45-14, ± 0.22 kPa; Validyne Corp., Northridge, CA), which was coupled to a carrier demodulator (Validyne CD19A; Validyne Corp.). Two sets of low-resistance two-way, non-rebreathing valves were attached to the respiratory system, next to the mouthpiece-pneumotachograph assembly to allow the subject’s inspired and expired laboratory air to be separated and to minimise apparatus dead space. Flow calibration was performed before commencing each session using a 3 L syringe pump, with volume standards applied at various flow rates [8]. Expiratory, inspiratory, and tidal lung volumes were determined from the digital integration of respiratory flow signals, with all volumes corrected and expressed as body temperature and pressure saturated with water vapour (BTPS).

Resting spirometry measures, including static tidal volume (\( \dot{V}_T \)), were collected during relaxed spontaneous breathing, with other volumes and capacities derived from standard lung volume manoeuvres [9]. Both data sets were collected over 60 s. Maximum voluntary ventilation (MVV) and FEV\(_1\) were also performed to assess the dynamic function of each subject’s respiratory system. All manoeuvres were completed in triplicate each day, with the three greatest volumes and flows achieved for each measure over the final 2 days of testing averaged and used for data analysis.

**Maximal exercise testing**

In an attempt to quantify whether perceived sports bra “tightness” impeded maximal exercise performance, maximal exercise tests were completed by the subjects in two breast support conditions: (i) while wearing a fitted new sports bra (SB), and (ii) while
wearing no external breast support other than a loosely fitting T-shirt (NB). Pilot testing established that running on a treadmill while wearing no external breast support resulted in breast pain severe enough to force some subjects to cease the trial after as little as 5 minutes of exercise. Therefore, maximal exercise tests were completed on an electronically braked cycle ergometer. As breast motion during cycling was minimal, this cycle ergometer protocol also enabled the effects of bra “tightness” to be examined in isolation of any breast momentum effects.

Exhaled air during cycling was carried into the open-circuit gas analysis system (SensorMedics2900, Yorba Linda, CA) to calculate \( \dot{V}O_2 \) measures with the gas analysers calibrated daily with two known gas concentrations (oxygen: 15.9–26.4%; carbon dioxide: 0–4.23%). During testing, subjects commenced cycling at 20 W for a 1 minute warm-up, with resistance then increasing in a ramped protocol of 6–7 W·20 s\(^{-1}\) until exhaustion. Each subject completed three maximal exercise tests (see Table 1), with results from the second and third day used for data analysis. During all exercise trials, each subject’s HR was monitored using a POLAR HR monitor (Polar Electro, Oy, Finland). To eliminate any chest wall restriction caused by the elastic belt of the HR monitor, while still enabling clear HR signals to be monitored, the chest strap of the monitor was removed and the monitor was attached to two electrodes, which were placed directly onto each subject’s torso below the level of breast tissue.

**Submaximal exercise testing**

In order to evaluate the effects of breast support on respiratory function during submaximal exercise and to determine whether breast momentum significantly impeded submaximal exercise performance, each subject completed submaximal exercise trials in three breast support conditions: (i) NB, (ii) SB, and (iii) wearing a fitted new fashion
bra (FB). The submaximal exercise trials were completed on a treadmill as each trial was approximately 5 minutes in duration and breast bounce was required for these trials to determine whether breast momentum developed by larger breasted subjects impeded respiratory function compared with their smaller breasted counterparts.

For submaximal exercise trials, the subjects stood on a treadmill (Quinton Instruments, Model 18-60-1, Seattle, WA) while wearing the nose clip and spirometry mouthpiece, with a 15 cm section of 5 cm diameter flexible tubing inserted between the mouthpiece and the pneumatograph to allow the subjects to move more freely during the submaximal trials. The size of the inserted tubing was restricted to minimise any effect on the system’s dead space. Treadmill speeds during the submaximal exercise trials were individualised to achieve 70% of each subject’s \( \dot{V}O_2 \)peak using the methods detailed in the American College of Sports Medicine’s Guidelines for Exercise Testing and Prescription [10]. Heart rate was monitored during each trial using the same procedures that were described for the maximal exercise testing.

Lung spirometry measurements during exercise commenced once the steady HR had been achieved at 70% of the subject’s \( \dot{V}O_2 \)peak. These measures of dynamic \( V_T \) are detailed in the resting spirometry protocol and were collected for 1 minute via the mouthpiece-pneumotachograph assembly, immediately followed by standard lung volume manoeuvres collected over an additional 1 minute. If the target HR was not achieved or the target HR was surpassed before the HR stabilised, the treadmill speed was adjusted accordingly.

To determine bra “tightness” during exercise, the external pressures that the bras applied to each subject’s chest region were quantified using two custom-designed piance-sensor pressure strips (nove\textsubscript{1}gmbh, Munich, Germany), which consisted of ten 1 cm\textsuperscript{2} sensors in parallel. The calibrated pressure strips were attached to each subject’s
torso, using micropore tape, directly under the elastic strap of the bra gore (see Figure 1).

![Figure 1: Pressure measuring strips attachment site.](image)

From the pressure strips, pressure data were collected (50 Hz) via a pliance mobile multi-interface box attached to a collection box (novelgmbh), interfaced with a personal computer. All data were collected via pliance Expert 8.2 online software (novelgmbh) with the sensor strips “zeroed” for each trial after they were attached to the subject. Pressure measurements were recorded for 15 seconds coinciding with the measures of $V_T$, allowing simultaneous changes in the pressure signal and breathing cycle to be monitored. However, as the pressure and spirometry systems could not be time locked, no assumption can be made in regards to the exact temporal relationship between pressure and spirometry measures in this study.
Subjects were required to rest for 10 min between each submaximal exercise trial. To quantify the perceived comfort of each bra, the subjects were asked to indicate bra comfort, using a visual analogue scale, immediately after the FB and SB trials. After all the submaximal trials were completed, each subject answered subjective questions (see Appendix E) to provide a qualitative assessment of the two bra styles. Full approval of the study was obtained from the University of Wollongong Human Research Ethics Committee (HE 99/180), and prior to testing all research participants provided written informed consent.

Means and SD were calculated for the two subject groups for each of the variables. Independent samples $t$-tests were then performed on the resting spirometry values to determine whether there were any significant ($p \leq 0.05$) differences in these data between the two breast size subject groups. A two-way repeated-measures ANOVA design with one within factor (breast support condition) and one between factor (breast size) was then used to determine whether either bra design or breast size significantly ($p \leq 0.05$) affected the respiratory, pressure, or comfort data obtained during the submaximal exercise trials, or exercise performance during the maximal exercise tests. If a significant main effect was achieved, a Tukey’s post hoc test was applied to the data to identify where the difference lay.

**RESULTS**

**Resting spirometry protocol**

Descriptive statistics pertaining to the resting spirometry variables, the physical activity scores calculated from the questionnaire, and the BMI measures obtained for the smaller and larger breasted subjects are presented in Table 2. As can be seen in the table, there was no significant difference between the larger (≥C cup) and smaller breasted (A cup)
subjects when assessing BMI ($p = 0.12$), suggesting that differences between the breast size groups could not be attributed to differences in overall height to weight ratios. In addition, there was no significant difference found between the estimated physical activity levels of the two groups ($p = 0.82$), suggesting that pre-testing physical activity levels did not affect testing results. Although no significant differences were found between the two bra groups in regards to lung volumes, the larger breasted subjects tended to display lower ERV measures compared with their smaller breasted counterparts (see Table 2), a finding that corresponds to previous research pertaining to obese individuals [6, 11-13]. In contrast, significant between-subject group differences were noted with respect to some of the temporal measures. That is, the larger breasted subjects had a significantly greater $V_T$/time of inspiration ratio with a decreased time of inspiration/total time of breath ratio compared with their smaller breasted counterparts (see Table 2).

No significant between-subject group difference was found when dynamic lung function was assessed (see Table 2). The smaller breasted subjects tended to display non-significant greater MVV measures compared with their larger breasted counterparts, with the recorded measures for the larger breasted subjects being significantly lower than the predicted values for these subjects when using the equation suggested by McArdle et al. [14]. With a decreased inspiratory time per total time ratio and with the greater $V_T$ per time of inspiration ratio found in the larger breasted subjects, it is likely that (i) this group consumed a greater $V_T$ within a similar inspiratory time or (ii) they took a shorter time to activate inspiration with the similar total respiratory time compared with the smaller breasted subjects (see Table 2). Results obtained from $V_T$, inspiratory time, and total time of breath and the duty cycle suggest
that smaller breasted subjects were likely to take longer to activate their inspiratory muscles in order to acquire the similar $V_T$ (see Table 2).

**Table 2**: Mean ($\pm$ SD) for the resting lung volumes obtained for the smaller and larger breasted subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All Subjects ($n = 22$)</th>
<th>Smaller Breasted ($n = 11$)</th>
<th>Larger Breasted ($n = 11$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass index</td>
<td>23.46 ± 2.87</td>
<td>22.48 ± 2.09</td>
<td>24.45 ± 3.51</td>
</tr>
<tr>
<td>Physical activity score</td>
<td>9.77 ± 2.72</td>
<td>9.91 ± 3.33</td>
<td>9.64 ± 2.11</td>
</tr>
<tr>
<td>Tidal volume (L, BTPS)</td>
<td>0.98 ± 0.22</td>
<td>0.94 ± 0.21</td>
<td>1.03 ± 0.23</td>
</tr>
<tr>
<td>Vital capacity (L, BTPS)</td>
<td>3.57 ± 0.57</td>
<td>3.67 ± 0.41</td>
<td>3.48 ± 0.71</td>
</tr>
<tr>
<td>Inspiratory capacity (L, BTPS)</td>
<td>2.46 ± 0.42</td>
<td>2.49 ± 0.40</td>
<td>2.43 ± 0.46</td>
</tr>
<tr>
<td>Expiratory reserve volume (L, BTPS)</td>
<td>1.11 ± 0.34</td>
<td>1.18 ± 0.17</td>
<td>1.04 ± 0.45</td>
</tr>
<tr>
<td>Inspiratory reserve volume (L, BTPS)</td>
<td>1.48 ± 0.38</td>
<td>1.55 ± 0.37</td>
<td>1.40 ± 0.40</td>
</tr>
<tr>
<td>Time of inspiration (s)</td>
<td>1.64 ± 0.49</td>
<td>1.66 ± 0.45</td>
<td>1.62 ± 0.54</td>
</tr>
<tr>
<td>Time of expiration (s)</td>
<td>2.40 ± 0.72</td>
<td>2.28 ± 0.66</td>
<td>2.50 ± 0.78</td>
</tr>
<tr>
<td>Total time of breath (s)</td>
<td>4.61 ± 1.6</td>
<td>4.41 ± 1.45</td>
<td>4.80 ± 1.88</td>
</tr>
<tr>
<td>Tidal volume/time of inspiration (L·s$^{-1}$)</td>
<td>0.68 ± 0.29</td>
<td>0.57 ± 0.07</td>
<td>0.79 ± 0.38$^a$</td>
</tr>
<tr>
<td>Time of inspiration/total time (duty cycle)</td>
<td>0.37 ± 0.04</td>
<td>0.38 ± 0.04</td>
<td>0.35 ± 0.03$^a$</td>
</tr>
<tr>
<td>Breathing frequency (breaths·min$^{-1}$)</td>
<td>14.57 ± 4.41</td>
<td>14.79 ± 3.92</td>
<td>14.34 ± 5.09</td>
</tr>
<tr>
<td>Resting minute ventilation ($V_E$, L·min$^{-1}$)</td>
<td>13.45 ± 2.40</td>
<td>13.22 ± 2.46</td>
<td>13.69 ± 2.44</td>
</tr>
<tr>
<td>Maximal voluntary ventilation (MVV, L·min$^{-1}$)</td>
<td>117.47 ± 27.18</td>
<td>124.85 ± 22.85</td>
<td>110.10 ± 30.17</td>
</tr>
<tr>
<td>Forced expiratory volume in 1 s (%)</td>
<td>86.63 ± 8.20</td>
<td>90.09 ± 7.82</td>
<td>83.16 ± 7.32</td>
</tr>
<tr>
<td>$V_E$/MVV</td>
<td>0.12 ± 0.04</td>
<td>0.11 ± 0.03</td>
<td>0.13 ± 0.04</td>
</tr>
</tbody>
</table>

$^a$ Significant difference between the smaller and larger breasted subjects ($p < 0.05$).

Resting $\dot{V}_E$ values revealed that subjects in both groups consumed only 11 and 13% of their maximum reserved ventilation (see resting $\dot{V}_E$/MVV ratio in Table 2). Babb [11] suggested that the $\dot{V}_E$/MVV ratio gave an indication of the mechanical ventilatory constraints within subjects, with our results again demonstrating no significant difference between the two bra size groups at rest.
Maximal exercise testing

Descriptive statistics pertaining to the maximal exercise testing variables obtained for the smaller and larger breasted subjects are presented in Table 3. These results confirm that subjects in both groups exercised maximally as indicated by peak respiratory rates of 41–47 breaths/min, peak HR of 177–180 beats per minute, and a shift toward fat and carbohydrate metabolism as indicated by the RER (see Table 3) [14]. During maximal exercise, subjects in both groups also consumed approximately 82 and 90% of their maximal reserved ventilation at peak exercise (see Table 3). However, no significant main effect of bra design was found during the maximal exercise tests when the data were pooled across subject groups (see Table 3). A significant main effect of breast size was found on the relative $\dot{V}O_2_{\text{peak}}$ measures, when the data were pooled across breast support worn, with the smaller breasted subjects recording significantly higher relative $\dot{V}O_2_{\text{peak}}$ measures during maximal exercise testing.

Some trends were also seen in the data, with Table 3 illustrating an increase in the $V_T$ measures during the NB conditions compared with the SB conditions ($p = 0.053$) when the data were pooled across subject groups, suggesting that sports bras may cause some restriction to $V_T$ during maximal exercise. A strong trend was also seen between the breast size groups in regards to the cycle ergometer resistance level achieved during maximal exercise tests ($p = 0.054$), with the larger breasted subjects reaching lower Watts in the maximal exercise test when compared with their smaller breasted counterparts. Maximal oxygen consumption measures also showed a trend with the smaller breasted subjects recording greater $\dot{V}O_2_{\text{peak}}$ measures when compared with their larger breasted counterparts ($p = 0.052$).
### Table 3: Mean (± SD) for the maximum exercise test results obtained for the smaller (n = 11) and larger breasted (n = 11) subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>No Bra</th>
<th>Sports Bra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smaller Breasted</td>
<td>Larger Breasted</td>
</tr>
<tr>
<td>Respiratory Rate (breaths/min)</td>
<td>44.82 ±11.51</td>
<td>41.18 ±8.29</td>
</tr>
<tr>
<td>Tidal Volume (l)</td>
<td>2.31 ±0.40</td>
<td>2.21 ±0.44</td>
</tr>
<tr>
<td>Heart Rate (beats/min)</td>
<td>178.00 ±9.56</td>
<td>180.36 ±11.68</td>
</tr>
<tr>
<td>Resistance (Watts)</td>
<td>214.18 ±33.11</td>
<td>189.27 ±22.03</td>
</tr>
<tr>
<td>VO2peak (ml/min)</td>
<td>3107.91 ±464.58</td>
<td>2741.27 ±334.69</td>
</tr>
<tr>
<td>VO2peak/kg (ml/kg/min)</td>
<td>49.84 ±6.15</td>
<td>40.76 ±4.47a</td>
</tr>
<tr>
<td>Respiratory Exchange Ratio</td>
<td>1.05 ±0.05</td>
<td>1.08 ±0.04</td>
</tr>
<tr>
<td>VE/MVV</td>
<td>0.82 ±0.16</td>
<td>0.86 ±0.19</td>
</tr>
<tr>
<td>Time to VO2peak (min)</td>
<td>10.66 ±1.64</td>
<td>9.42 ±1.06</td>
</tr>
</tbody>
</table>

**Abbreviation:** VE/MVV: minute ventilation: maximum voluntary ventilation ratio. 
*a* denotes a significant difference between breast size groups (*p* = 0.008).

### Submaximal exercise testing

Descriptive statistics pertaining to the submaximal lung volume and submaximal HR data obtained for the smaller and larger breasted subjects are presented in Table 4. The smaller breasted subjects displayed a significantly greater ERV when they were wearing sports bras compared with the FB condition (*p* = 0.019), although there was no effect of bra design noted on these parameters for the larger breasted women. Although other lung volumes and capacities and the sub-maximal HR were not significantly different for the smaller breasted subjects when comparing the FB and SB trials, the ERV
decrease was accompanied by non-significant increases in all inspiratory volumes and capacities in the FB condition (see Table 4). These results suggest that, during submaximal exercise, the smaller breasted subjects tended to breathe at a lower lung volume during the FB trials compared with the SB trial. Because airway resistance is higher while breathing at lower lung volumes [15], the fashion bra may have a negative impact on the respiratory function of smaller breast females during exercise.

Consistent with the resting spirometry measures, the smaller breasted subjects recorded significantly greater time of inspiration/total time of breath ratios when compared with their larger breasted counterparts when the data were pooled across bra design conditions ($p < 0.001$, see Table 2). These results suggest that, even during exercise, the inspiratory portion of respiration for the smaller breasted subjects contributed to a greater temporal proportion of the subject’s total breath when compared with the larger breasted subjects, irrespective of breast support worn. Mean (± SD) maximum pressure data recorded under the bras during the submaximal exercise trials for the smaller and larger breasted subjects are displayed in Figure 2. No significant main effect of either breast size or bra design was found for the maximal pressure, mean pressure, maximal force, or area data. However, significant interactions were found between breast size and bra condition when assessing both the maximal pressure the bra applied to the wearer ($p = 0.044$) and the pressure-time integral data ($p = 0.037$). That is, significantly higher maximal pressures and higher pressures over time were applied to the torso of the smaller breasted subjects when wearing the sports bra compared with the fashion bra, although this bra design effect was not noted for their larger breasted counterparts.
Table 4: Mean (± SD) for the submaximal lung volume data obtained for the smaller (n = 11) and larger breasted (n = 11) subjects.

<table>
<thead>
<tr>
<th>Variable</th>
<th>No Bra</th>
<th>Fashion Bra</th>
<th>Sports Bra</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smaller Breasted</td>
<td>Larger Breasted</td>
<td>Smaller Breasted</td>
</tr>
<tr>
<td>Vital Capacity (l, BTPS)</td>
<td>3.41 ± 0.47</td>
<td>3.33 ± 0.61</td>
<td>3.33 ± 0.47</td>
</tr>
<tr>
<td>Inspiratory Capacity (l, BTPS)</td>
<td>2.69 ± 0.40</td>
<td>2.69 ± 0.45</td>
<td>2.70 ± 0.34</td>
</tr>
<tr>
<td>Expiratory Reserve Volume (l, BTPS)</td>
<td>0.72 ± 0.22</td>
<td>0.64 ± 0.23</td>
<td>0.63 ± 0.22a</td>
</tr>
<tr>
<td>Inspiratory Reserve Volume (l, BTPS)</td>
<td>0.82 ± 0.31</td>
<td>0.86 ± 0.31</td>
<td>0.85 ± 0.23</td>
</tr>
<tr>
<td>VE/MVV</td>
<td>0.47 ± 0.12</td>
<td>0.52 ± 0.21</td>
<td>0.47 ± 0.11</td>
</tr>
</tbody>
</table>

*a* denotes a significant difference between bra support conditions (*p* = 0.025).

When assessing the results from the visual analogue scale, no significant main effect of either breast size or bra design was noted in the perceived comfort of the bra styles. However, 19 of the 22 subjects indicated that they would prefer to exercise while wearing the sports bra when compared with the fashion bra. Interestingly, three subjects indicated that the sports bra affected their ability to breath and two subjects stated that the sports bra affected their ability to exercise, as it was “tight.”

**DISCUSSION**

A primary aim of this study was to determine whether breast hypertrophy impeded exercise capacity or respiratory function in all active and resting states. Interestingly, the only between-subject group difference noted in the resting spirometry measures was a temporal difference, which implied that larger breasted subjects breathed in faster than their smaller breasted counterparts, relative to the time of their total breath. Although no research could be found in the literature discussing such a change between obese and
non-obese subjects, it could be suggested that the temporal difference found in this
study may be a direct result of the additional mass on the chest of the larger breasted
subjects, necessitating more muscular work to create the pressure gradient between the
lungs and the external environment for inspiration to occur. This increased muscular
work required by the larger breasted subjects may decrease the relative time required to
fill the lungs for a normal breath.

Although no significant between-subject group difference was found in regard to
dynamic lung function measures, the larger breasted subjects displayed lower MVV
predicted values. As no significant difference was found between subject groups with
respect to factors affecting the predicted values in the equations (standing height and
age), it is speculated that breast size may affect MVV, with increases in breast tissue
decreasing the amount of air subjects can maximally and repeatedly ventilate over a
short period of time. However, as no significant differences were found between the
smaller and larger breasted subjects in the resting state for both static lung volumes and
dynamic lung function, it is thought that breast size does not impede lung volumes in a
resting state. Therefore, although breast size does not appear to affect lung volumes in a
resting state, it does appear to influence the temporal pattern of breathing.

Although bra style did not significantly influence maximal exercise capacity,
results from this study implied that larger breasted subjects recorded significantly lower
relative $\dot{V}O_{2\text{peak}}$ when compared with their smaller breasted counterparts. Babb and
associates [6] reported similar results for obese subjects whereby their obese subjects
recorded significantly lower $\dot{V}O_{2\text{peak}} \cdot \text{kg}^{-1}$ measures when compared with their leaner
counterparts. As there was no significant difference in the BMI of the two bra size
subject groups and no significant difference between physical activity levels or intensity
of physical activity between breast sizes (see Table 2), it is suggested that larger
amounts of breast tissue may imitate those results seen in the overweight and obese population in terms of restricting maximal oxygen consumption. Therefore, although wearing a sports bra does not appear to significantly affect maximal exercise performance compared with wearing no bra, breast size appears to affect maximal exercise performance, whereby females with a larger amount of breast tissue record lower maximal oxygen consumption readings, when corrected for body weight, compared with their smaller breasted counterparts. However, it is acknowledged that physical activity levels and intensity were assessed in the present study using a questionnaire, which is limited by the need for self-reported responses. Therefore, possible between subject-group differences in physical activity may still have been a confounding factor and requires further investigation.

Although no literature could be found discussing the effects of tight bras on respiratory mechanics, Gehlsen and Albohm [16] reported that placing a 4 inch elastic wrap over the top of a supportive bra provided additional breast support compared with wearing the bra alone. Berger-Dumound [17] also stated that, in an evaluation of sports bras on the market, the most effective bras in limiting breast motion were not rated highly in comfort and that the most comfortable sports bras were among the worst performers in controlling breast motion. The author suggested that the bra’s ability to stretch had been compromised in the attempt to limit breast motion. In the present study, the pressure data confirmed that sports bras were “tighter” in that they caused significantly greater maximum pressure readings compared with the fashion bra, but only in the smaller breasted women. To explain this finding, the lengths of all bras used in the study were measured. Interestingly, in the smaller breasted bra size, the sports and fashion bras were very similar in length, with the sports bra measuring only 1 cm less in length when compared with the fashion bra. The increased pressures in this size
bra group could therefore be explained by the more rigid fabrics used in the gore of the sports bras in an attempt to increase compression of the breasts against the torso to minimise breast motion. In contrast, there was a greater discrepancy between the lengths of the larger bra sizes, whereby the sports bras actually measured longer in these sizes, up to 5 cm in the 14C size. Therefore, although the more rigid material of the sports bra should provide increased support, its increased length would have negated any increase in pressure against the torso. This assumption was further supported by the fact that significantly greater pressure-time integrals were recorded for the smaller breasted subjects compared with their larger breasted counterparts and with the smaller breasted subjects generating significantly greater pressure-time integrals while wearing the sports bras compared with the fashion bras.

When assessing the spirometry data, it appears that the differences in bra lengths and the resultant differences in bra pressure were not sufficient to cause significant differences in most lung volumes during submaximal exercise. The only differences found between the bra size groups and the bra styles were ERV differences between the sports and fashion bra conditions for the smaller breasted subjects and time of inspiration/time of breath difference between the two breast size groups. Although no literature could be found assessing different lung volumes as a result of bra tightness, the literature pertaining to regional lung ventilation suggests that the lower regional alveoli are ventilated to a greater extent than the upper regions and that chest expansion is therefore greater in the lower region of the chest, probably more so than where a bra rests when fitted correctly. There are also suggestions that restrictions to chest expansion (mainly in disease) in the upper chest regions do not have as great an effect on respiratory function as would lower regional restriction [18].
The difference in the time of inspiration/time of breath between the breast size groups was consistent with the resting spirometry measures and suggests that, at both rest and during exercise, larger breasted subjects appear to breathe in more quickly relative to the time of their total breath compared with their smaller breasted counterparts. As previously suggested, this may be due to additional muscular work during inspiration resulting in less time required for inspiration. However, the difference seen in the ERV between the fashion and sports bra trials for the smaller breasted subjects is more difficult to explain.

The significant decrease in the ERV during the fashion bra trial for the smaller breasted subjects is coupled with non-significant increases in inspiratory volumes and capacities. This would suggest that during the fashion bra trials, the smaller breasted subjects were breathing at a lower lung volume, which, according to Sharp and associates [13], would result in the $V_T$ occurring at a less compliant portion of the pressure-volume curve, requiring more muscular work during respiration. However, this finding is not consistent with the other results of this study, as external pressure on the chest was actually greater during the sports bra trial for these subjects, which could be a mechanism causing changes in ERV measures. Visual analogue scale recordings were also not significantly different between the two bra styles for the smaller breasted subjects, although 9 of the 11 smaller breasted subjects preferred to exercise in the sports bra. These findings suggest that the subjects may have been more relaxed during the sports bra condition compared with the fashion bra condition, allowing them to breathe more freely.

Sports bras are typically categorised into two design types: encapsulation bras (containing moulded cups that separate and support the breasts individually) and compression bras (designed to restrict breast movement by flattening the breasts against
Chapter 4

the body). No literature could be found assessing the effects of wearing a sports bra on respiratory function, regardless of the sports bra structure (encapsulation or compression). However, the limited scientific literature pertaining to sports bra design does suggest that encapsulation bras are more effective in limiting breast motion and related breast pain compared with compression bras [1], especially when worn by larger breasted women (sizes C+) [2]. Although the sports bra used in this study did not contain underwire in the A cup size, the bra was still an encapsulation bra as it had separate moulded cups. Whether encapsulation bras affect maximal oxygen consumption differently from compression bra types was not within the scope of the present study and warrants further investigation.

It is acknowledged that the results of the present study pertain to subjects who were professionally fitted for their bra before testing. Bra manufacturers have speculated that up to two thirds of Australian women wear the incorrect bra size (Deans, T., personal communication, 1999), with published literature suggesting that up to 80% of females wear the incorrect bra size [19]. Not only can a poorly fitted sports bra fail to reduce breast motion and resultant breast pain, Stamford [2] suggested that the sports bra must fit properly to ensure that the bra does not impede breathing by being too tight.

In summary, the results of this study suggest that wearing a correctly fitted sports bra does not significantly affect maximal exercise performance, nor does a correctly fitted sports bra appear to affect respiratory function during submaximal exercise, when compared with wearing either a fashion bra or no bra. Although the sports bra did appear to impart more maximal pressure on some subjects compared with the fashion bra, no significant difference was found between the comfort ratings for each bra.

In conclusion, bra size did affect some temporal measures of respiration during rest as well as maximal exercise ability, although breast motion did not affect
respiratory mechanics during submaximal exercise. Therefore, as no significant restriction of exercise performance or respiratory mechanics was found when subjects wore sports bras, it is recommended that active females use the additional breast support provided by a correctly fitted sports bra during physical activity. However, further research is recommended to investigate the effects of sports bras on other measures of performance, such as cardiovascular function during exercise, and to expand the subject base to include postpartum women. Such research is warranted to ensure that sports bras provide appropriate breast support for all women, irrespective of breast size, so that these women can exercise in comfort, without their bras impeding performance.
REFERENCES


Chapter 5

Effects of bra strap cushions and strap orientation on wearer comfort and sports brassiere efficacy.

This chapter is an amended version of the manuscript: Bowles K-A & Steele JR. Effects of bra strap cushions and strap orientation on wearer comfort and sports bra efficacy. Revised manuscript submitted to Medicine and Science in Sports and Exercise, October 2012.

ABSTRACT

Purpose: This study aimed to quantify bra shoulder strap pressures and to investigate how bra strap cushions moderated this pressure and resultant comfort; and to investigate the effects of variations in bra shoulder strap configuration on vertical breast motion, breast discomfort, shoulder pressures and comfort. Methods: Fourteen healthy females (C+ bra cup) ran on a treadmill wearing a sports bra under 5 strap conditions (no straps, traditional vertical alignment, crossed-back alignment, with and without bra strap cushions inserted under the straps). Bra shoulder strap pressure, vertical breast displacement (VBD), breast pain and shoulder comfort were measured during each trial. Results: Maximal pressures from 0.83 - 2.67 N/cm² and mean pressures from 0.52 - 1.06 N/cm² were recorded during running. The bra strap cushions only reduced maximal strap-shoulder pressure in the crossed-back strap orientation. VBD was significantly less in the crossed-back orientation compared to no straps and breast pain was significantly reduced in both the traditional and crossed-back orientations compared to the no strap condition. No significant between-condition difference was found in
shoulder comfort regardless of shoulder strap orientations, although the crossed-back strap orientation resulted in significant increases in shoulder force and mean pressure values compared to the traditional strap orientation. **Conclusion:** The bra shoulder strap cushion was not effective in decreasing the bra shoulder strap pressure due to design flaws that prevented it from adequately increasing the strap-shoulder contact area. However, modifying shoulder strap orientation from a traditional to a crossed-back configuration could alleviate the common problem of bra shoulder straps slipping off the shoulders of the wearer, without decreasing the overall efficacy of the sports bra in providing breast support.

**INTRODUCTION**

Since the 1980’s there has been an increasing number of research studies that have shown that a well-designed and well-fitted sports bra can reduce excessive breast motion and/or the associated exercise-induced breast pain that women often incur during physical activity [1-4]. In fact, clinicians and researchers have suggested that a supportive and well-fitted sports bra should be considered an essential piece of sporting equipment, not just a piece of underwear [5]. Previous research has revealed, however, that sports bras are not the most common breast support choice during exercise in young Australian women, whereby only 41% of female participants who were surveyed reported wearing a sports bra when they participated in physical activity [6]. When the deterrents to sports bra usage were further investigated, it was determined that these same women reported that they extremely disliked the shoulder straps of commercially available sports bras, mainly due to the shoulder straps cutting into and/or slipping off their shoulders [7]. More importantly, other reports have highlighted the substantial negative health implications associated with inappropriate bra shoulder strap fit and/or
design. These include the presence of keloid scarring on the skin directly under the shoulder strap [8] and soft tissue damage to the shoulder [9], described in further detail below, as a result of excessive downward pressure of the bra strap. Despite being the most disliked feature in current sport bra designs [6, 7] and the negative health consequences associated with badly designed or fitted bra straps, no research was found that systematically investigated the effects of modifying current shoulder strap designs on the comfort and support provided by a sports bra.

The purpose of shoulder straps is to hold a bra in place, not to provide support to the breasts [10]. However, it has been reported that some females, especially those with large breasts, tighten their bra straps in an attempt to hold their breast tissue off the anterior chest wall [11]. This causes much of the weight of the breasts to be borne by the bra shoulder straps and, in turn, causes the bra straps to exert high pressure on the shoulders of the wearer. This resultant pressure on the shoulders can not only lead to neck and shoulder pain but can also result in the development of deep bra strap furrows that are often seen in the shoulders of women with large breasts and are usually a direct result of narrow bra straps cutting into the soft tissues in the shoulders [9]. Additionally, the downward pressure exerted by the bra strap on the clavicle can narrow the costoclavicular passage and affect the neurovascular bundle [9], resulting in puffy blue hands and possible nerve dysfunction [12], including paraesthesia of the fifth digit of the hand [9]. It has been recommended that females who suffer any of these negative health consequences associated with high bra strap pressures should remove the shoulder straps from their bras, widen the straps or insert a bra strap cushion to decrease the pressure exerted on their shoulders and therefore reduce the related symptoms including neck and shoulder pain [9]. No published literature could be found, however, quantifying the pressures that bra shoulder straps exert on the shoulders of bra wearers,
or the effect of inserting a bra strap cushion on the bra strap-shoulder pressures or shoulder comfort of women.

Traditionally, bra straps were designed to traverse the shoulders of the wearer and attach to the girdle of the bra in a direct line with each nipple [13] (see Figure 1A). To prevent straps from slipping off the shoulder, however, this traditional strap configuration has been modified to include racer-back, crossed-back and T-bar designs (see Figure 1). Anecdotally, it is thought that the traditional shoulder strap orientation is more effective in limiting vertical breast motion compared to other strap configurations, particularly crossed-back strap designs, as a vertically positioned strap is directly aligned with the force vector generated by breast motion during activities such as running, which incorporate vertical trunk motion [14]. However, biomechanical testing completed at the Australian Institute of Sport (AIS) in 2006 suggested that a crossed-back strap design was more effective in limiting breast motion than the traditional shoulder strap orientation, although no details of this investigation are available in the published scientific literature [15]. Although one publication has investigated the effects of lift and gather on breast tissue as a result of differing strap conditions [16], despite the finding that the bra shoulder strap slipping off the shoulder of the wearer was one of the most disliked features in current sports bra designs (6), no research could be found that systematically investigated the effect of modifying shoulder strap orientation on vertical breast motion, resultant exercise-induced breast pain and/or shoulder comfort.

Given the lack of research pertaining to the design of sports bra straps, as well as the negative health consequences associated with inappropriate bra strap design and fit, the purpose of this study was to: (i) quantify the pressures that bra shoulder straps exert on the shoulder of the wearer and to investigate how bra strap cushions moderate this
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pressure and resultant shoulder comfort; and (ii) investigate the effects of variations in bra shoulder strap configuration (traditional versus crossed-back orientation) on vertical breast motion, exercise-induced breast discomfort and shoulder pressure and comfort. Based on previous literature and biomechanical principles it was hypothesized that: (i) inserting bra strap cushions would decrease the pressure that bra shoulder straps exert on the shoulder of the wearer, in turn, increasing shoulder comfort; and (ii) a traditional shoulder strap orientation would be associated with less vertical breast motion and shoulder pressure and, in turn, less exercise-induced breast discomfort, than a crossed-back strap alignment.

Figure 1: Sports bra shoulder strap orientations: A) traditional shoulder strap; B) crossed-back shoulder strap; C) racer-back; and D) T-bar shoulder strap.
METHODS

Participants

Fourteen healthy active females (mean age = 24.8 ± 3.8 years; height = 166.4 ± 5.3 cm; mass = 66.6 ± 9.1 kg), who were professionally measured as a C+ bra cup, were recruited for this study from the staff and students at the University of Wollongong. Before inclusion, the Chief Investigator [K-AB] fitted all potential participants in the test bra (Berlei Ultrasport Elite) in accordance with the sports bra manufacturer’s sizing manual [17]. The most common bra size amongst the participants was 14C (6 out of 14 participants) with the band width size ranging from a 10 to a 14 (Australian sizing), and the cup measuring as either a C or D cup size. Participant inclusion was limited by age (aged 20 to 35 years), bra size (C cup size or larger), any current or previous pregnancies, any breast surgery or interventions, or any musculoskeletal disorder that would affect running or walking. To avoid breast pain due to menstruation, the participants were tested within the week prior to the onset of their menses. The University of Wollongong Human Research Ethics Committee approved all recruiting and testing procedures (HE02/071), and all subjects gave written informed consent to participate in the study.

Experimental conditions

Five experimental conditions were tested during the study, with participants completing one running trial for each condition. A no strap condition was used as a base measurement. A traditional vertical strap alignment and a crossed-back strap alignment, with both strap alignments tested with and without the inclusion of a bra strap cushion formed the other four experimental conditions. The test bra used during all trials was the Ultrasport Elite sports bra (Berlei, Pacific Brands, New South Wales, Australia).
This sports bra was selected as the test bra because the strap configuration could be easily modified while keeping the rest of the bra structure and materials consistent throughout every trial (see Figure 2). The test bra was composed of white nylon, cotton, polyester and Lycra, contained underwire and was encapsulating in design. All participants wore a new bra for their test session to ensure that there were no adverse effects of either wear or washing on the bras, and the conditions were randomly allocated to ensure that bra order did not affect any results.

![Figure 2](image)

**Figure 2:** Test bra used in this experiment (Berlei Ultrapor Elite) with the (A) traditional shoulder strap orientation (with strap cushions inserted); (B) no strap condition; and (C) crossed-back strap orientation.

Commercially available, oval shaped shoulder strap cushions (Amoena #192 shoulder cushions, Mount Waverley, Australia) were used for the strap cushion conditions. The cushions (130 mm x 50 mm) consisted of a foam rubber laminated with nylon tricot (see Figure 3), with Velcro attached to the anterior aspect to hold the strap
of the bra in position on the cushion. The cushion was positioned on the crest of each participant’s shoulders (see Figure 2A); with all participants using the same white pair of cushions for each cushion trial.

![Image of shoulder cushions](image)

**Figure 3:** The bra shoulder cushions used in this experiment (Amoena #192 shoulder cushions, Mount Waverley, Australia).

**Experimental procedures**

All testing was conducted in the Biomechanics Research Laboratory at the University of Wollongong, and the participants wore their own running shorts and shoes during all testing for each bra strap condition. Although all participants were experienced treadmill runners, they were firstly provided with a familiarization trial on the laboratory treadmill (Powerjog GX 100, Expert Fitness UK, Wales, UK). They were then asked to run at a comfortable self-selected speed that they could maintain for 10 minutes without experiencing fatigue (mean speed = 7.6 km/hr; range = 6.3 - 8.5 km/hr). A self-selected speed was chosen as pilot testing and the literature both suggest that requiring participants to run at a standardized speed that differs from their self-selected speed can affect their gait pattern [18], which may in turn affect their breast motion. All data were collected on the one day for each participant, with participants
required to complete five running trials of 5 minutes and 15 seconds in duration. Participants were given a 10 minute rest period between running trials, during which the next bra shoulder strap set up was prepared.

**Vertical breast displacement**

The vertical displacement of each participant’s breasts relative to their torso were monitored during each running trial by tracking light-emitting diodes (2-mm diameter) placed directly onto the participant’s skin overlying the sternal notch, using double sided tape (3M), and over micropore tape (3M) placed in the centre of each participant’s nipples. These marker placements were deemed the most appropriate as previous research has shown nipple motion to provide a good representation of vertical breast motion [3]. As previous research has shown a strong association with vertical breast motion and resultant breast pain [1-4], vertical breast displacement was deemed suitable to represent breast motion in this comparative study.

The three-dimensional position of each light-emitting diode was tracked using an OptoTRAK (3020) motion capture system (Northern Digital, Incorporated, Ontario, Canada; duty cycle 75%, voltage 9 and marker frequency 200 Hz). In each condition, the treadmill speed was gradually increased to the participant’s pre-selected running speed with data collected 5 minutes into the trial for a 15 second period during which the participant was running with a consistent, “steady state” stride pattern. The treadmill speed was then decreased to a stop.

Vertical breast displacement for each trial was calculated (in centimeters) from the displacement data by removing torso motion (characterized by the sternal notch marker) from the nipple motion in the vertical plane. The mean of the 10 most representative vertical breast displacement values, derived from cycles in which no marker data were
Breast pain and shoulder comfort

To quantify the exercise-induced breast pain and shoulder comfort perceived by the participants during each trial, the participants were asked to indicate their pain and comfort level immediately after each trial using a 100 mm long Visual Analogue Scale, which has been reported to be valid and reliable in previous research [19]. Breast pain was rated from “0” indicating no breast pain to “100” indicating the worst breast pain possible and shoulder comfort was rated from “0” indicating the most comfortable possible to “100” indicating the least comfortable possible. After completing all trials, participants answered qualitative questions regarding their overall bra comfort and their preferred shoulder strap configuration (see Appendix F).

Bra shoulder strap pressure

The force, contact area, and pressure exerted by the bra shoulder strap onto the shoulder of each participant were collected using two custom-designed pliance-sensor pressure strips (novelgmbh, Munich, Germany) as described previously in Bowles et al. [20] (see Figure 2). These strips consisted of ten, 1 cm² sensors in parallel and were attached to the inner aspect of the bra shoulder strap or the shoulder cushion, always in direct contact with the participant’s shoulder. The sensor was positioned to lie on the crest of the shoulder, with even amounts of the sensor strip located on the anterior and posterior aspects of the shoulder. The sensor strips were “zeroed” once attached to the bra shoulder strap, prior to the bra being placed on the participant. Data from the pressure strips were collected at 50 Hz using a pliance mobile multi-interface box attached to a
collection box (novel gmbh, Munich, Germany), and interfaced with a personal computer using the pliance Expert 8.2 online software (novel gmbh, Munich, Germany) for data collection. The pressure measurements (N/cm²) were recorded for 15 seconds coinciding with the vertical breast displacement measures, 5 minutes into the running trial. Although measures of pressure were recorded simultaneously with vertical breast displacement, similar to previous research published [20], the data collection equipment for both measures could not be time-locked and therefore no assumptions of the exact temporal relationship between these measures can be made. Sensor data collection zones or “masks” were established prior to data collection using the novel-win software (novel gmbh, Munich, Germany) to group the ten sensors in each strip. As a result of pre-establishing the masks, the following variables were derived through the pliance Expert 8.2 online software (novel gmbh, Munich, Germany): contact area (the sum of all of the loaded sensors, in both strips, during the time of the trial); maximum force (the total force measured over both strips); mean and maximum pressure and pressure-time integral (measured and calculated for each strip with software displaying the highest value).

**Statistical analysis**

Mean and standard deviation values were firstly calculated for each of the five experimental conditions (no strap, traditional and crossed-back orientation, with and without strap cushions) for the average vertical breast displacement, the VAS scores charactering breast pain and shoulder comfort, and the bra shoulder strap pressure data. To quantify the effects of inserting the bra cushions under the bra straps and how any effects were moderated by strap orientation, the shoulder comfort, mean and maximal pressure, force, contact area, and pressure-time integral data were analysed using an
ANOVA design with two within factors (strap cushion: with and without; and strap orientation: traditional and crossed back).

To determine the effect of bra shoulder strap orientation on vertical breast displacement, mean pressure, pain and comfort scores, a one-way repeated-measures ANOVA design was used with the shoulder strap orientation (no-strap, traditional, crossed-back) as the independent variable. Where a significant difference was found, Bonferroni pair-wise comparison tests were conducted to identify where the difference lay, with the alpha level adjusted for the number of comparisons in the test by the statistic software. All statistical analyses were deemed significant to a level of $p \leq 0.05$ (SPSS, V. 19).

RESULTS

Effect of bra strap shoulder cushion

During the running trials maximal pressures ranging from 0.83 - 2.67 N/cm$^2$ and mean pressures ranging from 0.52 - 1.06 N/cm$^2$ were exerted by the bra straps on each shoulder of the wearer. Unexpectedly, there was no significant main effect of shoulder strap cushion on any of the contact area, force, pressure or comfort results. However, there was a significant strap cushion x strap orientation interaction ($p = 0.038$) whereby, although there was no change in pressure with and without the cushion under the traditional strap orientation, in the crossed-back orientation the maximal pressure generated at the bra strap-shoulder interface was significantly lower when the cushion was inserted compared to when there was no strap cushion (see Table 1).
**Table 1:**  Mean (± SD) data for the variables obtained during the running trials from the pressure measuring strips and the shoulder comfort scores, when the participants (n = 14) wore the bra in the crossed-back and traditional strap orientation, with and without the bra strap cushions inserted under the straps.

<table>
<thead>
<tr>
<th></th>
<th>Crossed-back strap orientation</th>
<th>Traditional strap orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without cushion</td>
<td>With cushion</td>
</tr>
<tr>
<td>Mean pressure (N/cm²)</td>
<td>0.77 ± 0.14</td>
<td>0.76 ± 0.16</td>
</tr>
<tr>
<td>Maximal pressure (N/cm²)</td>
<td>1.49 ± 0.52&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.17 ± 0.31&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Force (N)</td>
<td>12.14 ± 2.86</td>
<td>12.80 ± 2.55</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>19.2 ± 1.6</td>
<td>19.6 ± 0.8</td>
</tr>
<tr>
<td>Pressure-time integral (N/cm²/s)</td>
<td>7.72 ± 1.96</td>
<td>6.67 ± 1.80</td>
</tr>
<tr>
<td>Shoulder comfort (0-100)</td>
<td>9 ± 12</td>
<td>8 ± 11</td>
</tr>
</tbody>
</table>

<sup>a</sup> indicates a significant difference in the maximal pressure generated at the bra strap-shoulder interface in the cross-back strap orientation, with and without a strap cushion.

**Effects of bra strap orientation**

There was a significant main effect of modifying the bra shoulder strap orientation on vertical breast displacement during running ($p = 0.012$). Bonferroni pair-wise comparisons revealed that vertical breast displacement was significantly less in the crossed-back strap orientation compared to the no strap condition ($p = 0.015$; see Table 2). However, there was no significant difference in vertical breast displacement between the traditional strap orientation and the no strap condition ($p = 0.076$), although this value approached significance. Nor was there any significant difference between the traditional strap orientation and the crossed-back strap orientation ($p = 0.834$) in reducing vertical breast motion during running.
Table 2: Mean (± SD) data for the vertical breast displacement, breast pain, shoulder comfort and mean pressure generated at the bra strap-shoulder interface when the participants (n = 14) wore the bra in the crossed-back orientation, the traditional strap orientation, and with no straps.

<table>
<thead>
<tr>
<th></th>
<th>Crossed-back strap orientation</th>
<th>Traditional strap orientation</th>
<th>No strap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement (cm)</td>
<td>4.08 ± 1.25a</td>
<td>4.21 ± 1.16</td>
<td>5.01 ± 1.58a</td>
</tr>
<tr>
<td>Breast Pain (0-100)</td>
<td>7 ± 12a</td>
<td>13 ± 15b</td>
<td>39 ± 27a,b</td>
</tr>
<tr>
<td>Shoulder Comfort (0-100)</td>
<td>11 ± 12</td>
<td>15 ± 16</td>
<td>12 ± 16</td>
</tr>
<tr>
<td>Shoulder Pressure (N/cm²)</td>
<td>0.77 ± 0.14c</td>
<td>0.67 ± 0.18c</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Significant difference between crossed-back and no strap orientation.
* Significant difference between traditional strap and no strap orientation.
* Significant difference between traditional strap and crossed strap orientation.

A significant main effect of shoulder strap orientation was also noted on breast pain during the running trials (p = 0.001; see Table 2). Post hoc analysis revealed a significant reduction in breast pain when participants used both the traditional and crossed-back strap orientations (both p = 0.002) compared to the no strap condition. No significant difference was found, however, between the two strap orientations (p = 0.259) in resultant exercise-induced breast pain. In addition, no significant between-condition difference was found in the shoulder comfort measures regardless of shoulder strap orientations (p = 0.453), although the crossed-back orientation resulted in significant increases in mean pressure values when compared to the traditional strap orientation (p = 0.011). When questioned on overall bra comfort, 11 of 14 participants reported that the crossed-back shoulder orientation was more comfortable for them than the traditional shoulder strap orientation.
DISCUSSION

This unique research is the first study published in the scientific literature to quantify the pressures that bra shoulder straps exert on the shoulder of bra wearers and to determine whether the insertion of a bra shoulder strap cushion could moderate these pressures. The effects of bra strap cushions on bra shoulder pressures, as well as the effect of changes in bra shoulder strap orientations on breast motion, and exercise-induced breast discomfort are discussed below.

Effects of bra shoulder strap cushion

The pressures exerted by a single bra strap onto the participants’ shoulders’ (mean range 0.52 - 1.06 N/cm²; maximal pressure range 0.83 - 2.67 N/cm²) might initially seem low and, therefore, inconsequential. However, Jones and Hooper [21] cited previous work suggesting that continuous pressure values of up to 14 kPa (1.4 N/cm²) should be avoided to prevent tissue damage whilst carrying a loaded backpack. Furthermore, measured values from the current study are in line with the mean values (70 - 110 mmHg; 0.933 - 1.47 N/cm²) that have been reported previously in children, for shoulder-surface contact pressures applied by a backpack during walking, loaded with 10% of the child’s body mass [22]. Of most concern is that all these measures are greater than 30 mmHg (0.40 N/cm²), which has been reported as the pressure threshold at which skin blood flow can be occluded [22]. Given that women typically wear a bra on a daily basis during most of the hours they are awake, these pressures exerted by the bra strap onto the wearer’s shoulder have to be sustained for numerous hours every day, explaining the development of deep furrows in the soft tissue structures of the shoulder in some women over time [1]. Furthermore, pressure values in the present study were measured for the shoulder straps of a sports bra that are traditionally wider than the
straps of a fashion bra. As thinner bra straps would have less area to dissipate the same force, these current pressure measures are likely to underestimate the pressures exerted on the shoulders of women during activities of daily living.

Contrary to our hypothesis, inserting the bra shoulder strap cushion did not significantly decrease the mean shoulder pressure, contact area or force measures exerted on the shoulder of the wearer. In fact, the strap cushion only significantly reduced the maximal pressure exerted on the shoulder whilst it was inserted under the crossed-back bra shoulder strap compared to the traditional shoulder strap orientation. We anticipated that the shoulder strap cushions would increase the area over which the shoulder strap forces could be distributed and, in turn, reduce the resultant pressures. However, unexpectedly, there was only a negligible increase in the contact area between the bra strap and shoulder when the bra strap cushion was inserted, and this was accompanied by a similarly small increase in force, such that there was no substantial change in the mean pressures exerted on the shoulders during the running trials when the shoulder strap cushion was inserted. Visual inspection of the strap cushions revealed that the lateral portions of the cushions tended to lift off the wearers’ shoulders, particularly in the traditional shoulder strap orientation condition, and therefore did not increase the actual bra strap-shoulder contact area. Interestingly, in the crossed-back shoulder strap orientation, the bra strap traverses over the trapezius muscle on the posterior aspect of the shoulder, rather than the bony spine of the scapula in the traditional strap orientation. Traversing the relatively flat muscle belly permitted the shoulder strap cushion to be placed in a more level position compared to when traversing the bony prominence in the traditional strap orientation. This, in turn, appears to allow the cushion to be more effective in the cross-back shoulder orientation, as evidenced by the significant reduction in the maximal shoulder pressure in this
condition compared to the traditional strap orientation. Based on these results we recommended that strap cushions should be redesigned to enable them to remain flat against the shoulder so that they can effectively increase the area over which the forces from the shoulder straps are exerted.

**Effects of bra strap orientation**

Contrary to our hypothesis and the anecdotal beliefs about strap orientation [14], the traditional shoulder strap orientation was not more successful in decreasing vertical breast motion or decreasing breast pain during the running trials, compared to the crossed-back strap orientation. Although there were no significant differences in these variables when comparing the two experimental shoulder strap orientations, only the crossed-back shoulder strap orientation significantly reduced vertical breast motion relative to the no strap condition. With no other scientific literature found investigating bra shoulder strap orientations, we can only speculate as to why the results of this study were contrary to our hypothesis, yet consistent with the results found in the AIS investigation [15]. As stated previously, the shoulder straps of a bra should be used to anchor the bra rather than support the breasts [10], with breast support provided by the bra band. We speculate that if the bra band is well structured and provides the necessary breast support, orientation of the shoulder straps might not be as important in providing breast support as other sections of the bra. For example, McGhee and Steele [24] reported that increasing the elevation and compression of the breasts by innovative cup design in a sports bra decreased breast motion and related breast pain, and improved sports bra comfort. Furthermore, Starr *et al.* [25] also stressed the importance of an encapsulating cup design for a sports bra to limit breast motion, rather than a compression style sports bra. The material structure of the shoulder straps in this study
was consistent across the two experimental strap orientations with the modification in strap orientation resulting in no significant difference in the ability of the shoulder strap to reduce vertical breast displacement and related pain. Therefore, it is suggested that the material composition of the shoulder straps may be more important in holding the bra in place compared to the strap orientation, although this notion warrants further investigation.

Consistent with the vertical breast displacement data, and the previous findings of a strong association between breast motion and exercise-induced breast pain [1-4], there was a significant decrease in breast pain in both the traditional and crossed-back strap orientations, when compared to the no strap condition. As exercise-induced breast pain can be severe enough to cause women to cease participating in physical activity, designing sport bras that can limit this breast pain is vital to improve women’s participation rates in physical activity and resultant overall health. As there was no significant difference between the strap orientations in terms of decreasing exercise-induced breast pain, we suggest that either strap orientation has the potential to reduce exercise-induced breast pain for active women, relative to a strapless bra.

Interestingly, the crossed-back shoulder strap orientation imparted significantly more mean pressure and force on the shoulder of the wearer when compared to the traditional shoulder strap orientation; although these increases were not reflected in the shoulder comfort measures. We speculate that the increase in mean pressure in the crossed-back strap orientation was not functionally high enough to affect overall shoulder comfort. In fact, 11 out of the 14 research participants reported after the running trials that they preferred the crossed-back orientation over the traditional strap orientation.
Two of the participants reported they perceived that the shoulder straps in the traditional orientation were not as “tight” over the shoulder as they would usually wear, possibly affecting the resultant pressure and comfort reading for this condition. As the posterior elastic section of the bra shoulder strap (visible in Figure 2) had to be long enough to traverse the width of the back to attach to the opposite side in the crossed-back orientation, it was too long to be tightened to the participant’s preference in the traditional strap orientation trial for these two participants. Although this is a limitation of the current study, this problem was only apparent for two participants, and the measured vertical breast displacement during the running trial for one of these participants was actually greater with the crossed-back orientation, when compared to the traditional strap orientation.

In conclusion, the insertion of a commercially available bra shoulder strap cushions was not effective in decreasing the pressure that the bra shoulder straps exerted on the wearer. However, further research is recommended to determine whether redesigning the strap cushions could increase the effective bra strap-shoulder contact area and enable the cushions to alleviate bra shoulder pressures and prevent bra straps digging into the shoulders of sports bra wearers. In addition, assuming that the band of a bra provides sufficient support, modifying shoulder strap orientation from a traditional to a crossed-back configuration could alleviate the common problem of bra shoulder straps slipping off the shoulders of the wearer, without decreasing the overall efficacy of the sports bra.
REFERENCES


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Chapter 6

General discussion, conclusions and recommendations for future research.

GENERAL DISCUSSION

With changes in worldwide Government legislation such as Title IX of the Federal Education Act in the USA (1972) and the Commonwealth Sexual Discrimination Act in Australia (1984), more equal opportunities have resulted for females who wish to participate in sport. Coupled with advancement in textiles technologies, history reports that the first sports bra was designed in the late 1970’s [1, 2], resulting in initial subjective and laboratory-based assessments of sports bras in the 1980’s [3-7]. With further textile and design advancements and a greater appreciation for sex specific needs in sporting equipment, scientific laboratory-based research has since expanded to investigate the effect of various bra designs not only on breast motion [8] and related breast pain [9-14], but also on running kinetics [15] and kinematics [10, 13, 16], jumping [12] and star jumping [17]. Although this research has promoted the use of sports bras for breast support during physical activity, no research could be found assessing the level of sports bra usage to ascertain whether the results of the scientific research have been translated from the laboratory to the general female population.

The overall aim of this thesis was to identify factors that influence breast support choices made by Australian females when they participate in physical activity, and to investigate factors that may deter females from using sports bras to gain sufficient breast support during physical activity. To achieve this overall aim, this thesis was structured into two sections. Section A of the thesis utilised a mail-out survey to investigate the breast support choices of Australian females when they participate in
physical activity (Chapter 2) and to identify design features that deter females from wearing sports bras during physical activity (Chapter 3). Section B then further investigated two of the identified barriers to sports bra usage in laboratory-based studies. This included (i) quantifying the perceived tightness of sports bras around the chest of the wearer and the effect on breathing ability during physical activity (Chapter 4); and (ii) the effect of modifying sports bra shoulder strap design to prevent the shoulder strap from digging into or slipping off the shoulder of the wearer without affecting the overall efficacy of the sports bra (Chapter 5).

Section A

Although sports bras have been advocated in the scientific literature to provide additional breast support during physical activity, the results of the mail-out survey indicated that only 41% of respondents wore a sports bra during physical activity. The most frequently reported reason for not wearing a sports bra was that respondents did not feel that they needed to wear one (27%). Therefore, it is suggested that better education is needed to promote the use of sports bras during physical activity, with factors such as the age group and bra size of the target audience considered when developing these education programs (see Chapter 2). Furthermore, although only 41% of respondents used a sports bra for breast support during physical activity, 71% of respondents had tried a sports bra at some time (see Chapter 2), suggesting consumer dissatisfaction with current sports bra designs. Sports bra consumer likes and dislikes were therefore further investigated in Chapter 3, with the results identifying possible deterrents to wearing a sports bra. Two main design features that deterred the females from wearing sports bras included: (i) the perception that sports bras are too tight around the chest, possibly affecting performance by impeding respiration and causing
discomfort; and (ii) the perception that the current sports bra shoulder strap designs are uncomfortable. Although some of these perceptions may be linked to poor bra fit, it is imperative that bra tightness around the chest and shoulder strap designs be further investigated to develop evidence-based recommendations for improving sports bra designs so that females of all breast sizes are able to participate in physical activity comfortably.

**Section B**

As highlighted in Chapter 3, perceived bra tightness around the chest, and the perception that this restriction can affect respiratory function, lung volumes and exercise performance, was a potential deterrent to wearing a sports bra. Therefore, in Chapter 4 the pressure exerted by the bra band on the chest of the wearer and the effect of breast hypertrophy on lung volumes and exercise performance were both assessed. Although breast size did not significantly affect lung volumes in a resting state, there was a difference in the temporal patterns of breathing between the participants of different breast sizes, whereby participants with larger breasts breathed in faster than their smaller breasted counterparts. In addition, breast size negatively affected the predicted maximum voluntary ventilation measures, showing a decrease in the amount of air that participants with larger breasts could maximally and repeatedly ventilate over a short period of time. Both these differences may be a result of the participants with larger breasts already utilising greater amounts of diaphragmatic and inspiratory muscle activity during resting spirometry [18] and therefore forced increases cannot be sustained as easily as they are in participants with smaller breasts. Such a finding has not been previously reported in the literature and adds to the current body of knowledge in this field.
In addition, breast size significantly affected maximal exercise performance, whereby females with larger breasts recorded lower relative maximal oxygen consumption readings, compared to their smaller breasted counterparts. Babb et al., [19] reported finding similar results in their research with obese participants, suggesting that breast hypertrophy may imitate some of the effects of obesity with respect to maximal exercise performance. Interestingly, bra style had no effect on maximal exercise ability, suggesting that a correctly fitted sports bra does not negatively affect maximal exercise performance.

Results from this thesis also indicated that, although the sports bra imparted more pressure on the chest of the participants with smaller breasts when compared to the fashion bra, only some changes were evident in the spirometry measures between the two different bra styles. Although no previous research could be found to explain such findings, Tucker and Jenkins [20] suggested that restriction to chest expansion in the upper chest regions (around where a bra would be positioned) did not affect respiratory function, whereas restriction to the lower regions of the chest wall does affect respiratory function. As the results of the present thesis also indicated that chest comfort was not negatively affected by bra tightness, it is suggested that correctly fitted sports bras do not negatively affect maximal or submaximal exercise, and were deemed the most comfortable form of breast support by most of the participants in this thesis.

As Chapter 3 highlighted current sports bra shoulder straps as extremely disliked by the survey respondents, the effect of modifying shoulder strap orientation and the use of strap cushions on the ability of an encapsulation bra to provide breast support while being comfortable to wear was also investigated. Although it has been suggested that inserting a strap cushion under bra straps could alleviate the problem of bra straps digging into the shoulders [21], the commercially available bra strap cushion tested in
this thesis was not effective in decreasing pressure at the bra strap-shoulder interface. The design of the shoulder strap cushion is imperative, as in this thesis, the cushion did not increase the area over which the force generated by the shoulder strap was dissipated. Therefore the strap cushion did not decrease the resultant shoulder strap pressure and, in turn, did not alleviate the problem of the bra shoulder strap digging into the shoulder.

As the bra shoulder strap slipping off the shoulder of the wearer was also highlighted as one of the most disliked features of a sports bra, the effects of modifying bra strap orientation on breast support and comfort were also investigated. Vertical breast displacement and related breast pain and shoulder discomfort were measured while participants wore a sports bra under three straps conditions: traditional vertical strap orientation, cross-back strap orientation and no straps. Results of this study revealed that the cross-back strap orientation significantly reduced vertical breast displacement compared to the no strap condition. Although no scientific literature could be found assessing the efficacy of varying bra strap orientations, these finding supported an unpublished report [22] that claimed that a cross-back strap orientation could reduce vertical breast displacement more than a traditional strap orientation. As this reduction in vertical breast displacement was not accompanied by any significant increase in breast pain or shoulder discomfort, it is suggested that modifying a traditional shoulder strap orientation to a cross-back strap orientation could alleviate the issue of the bra straps slipping off the shoulders, without negatively affecting the overall efficacy of the bra in terms of providing breast support.
LIMITATIONS AND DELIMITATIONS

In addition to statements already listed in each chapter, the following are acknowledged as limitations and delimitations of this thesis:

Section A

1. Although it would be optimal to question every member of the population when completing epidemiological research (current study population: Australian females aged between 20 and 35 years), time, financial and logistical restraints made this impossible. For this reason only a sample of the population was questioned for this survey, with results inferred for all Australian females aged between 20 and 35 years.

2. Every effort was made to recruit a random and unbiased sample of the population to complete the survey. However, the survey method restricted potential respondents to only include females with a telephone listing in the White Pages telephone books.

3. Due to the requirements of completing a self-administered survey, only females who could read and write English were potential respondents for this study, which may lead to an education and ethnic bias in the responses.

Section B

4. Due to the large time commitment required from the participants for the laboratory testing sessions, and the sensitive nature of the testing, the participants in this study may represent only a sample of the female population.

5. Participants completed the submaximal exercise trials on a treadmill due to the need to walk/run at a set speed whilst breathing through a mouthpiece. Although treadmills are readily used in scientific experimentation, they do not
replicate the biomechanical and physiological characteristics of over ground running.

6. Although it would be ideal to complete maximal and submaximal exercise tests using the same equipment, treadmill running/walking was required during the submaximal tests to evaluate the effects of breast bounce on variable outcomes. However, treadmill running in a no support condition for greater than 5 minutes (which was required in the maximal exercise tests) often results in exercise-induced breast pain and, therefore, maximal exercise tests were conducted using a cycle ergometer.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this thesis, the following conclusions and recommendations are made:

1. Sports bras are not the most popular breast support choice during physical activity. It is recommended that international standards to classify the level of breast support provided by various sports bras be scientifically developed so that women can more easily identify bras that are designed to provide adequate breast support during different types of physical activity.

2. Although perceived tightness of a sports bra around the chest of the wearer was identified as a deterrent to wearing a sports bra, correctly fitted sports bras do not negatively affect respiratory function during exercise. Furthermore, although the sports bra imparted more pressure than a fashion bra for the participants with smaller breasts, the sports bra was the preferred style of breast support choice for most participants in this study. It is therefore, recommended that females seek professional fitting advice when purchasing bras to ensure the
bra band is correctly fitted and that bra designers ensure that the bra chest band contains sufficient elastic material to allow chest expansion, when the wearer is participating in physical activity, without negatively affecting the bra structure.

3. Breast hypertrophy negatively affected maximal exercise performance of the participants with larger breasts compared to their counterparts with smaller breasts. It is recommended that the effects of breast size on respiratory mechanics should be taken into consideration when planning exercise programs for females with larger breasts.

4. One of the most disliked features of current sports bras was the bra shoulder straps digging into or slipping off the shoulder of the wearer. Modifying the shoulder strap from a traditional vertical strap orientation to a cross-back strap orientation allowed the bra to be more effective in limiting vertical breast motion compared to a no strap condition, without any concurrent increase in shoulder discomfort. A cross-back strap orientation would also eliminate the problem of bra straps slipping off the shoulders. It is therefore recommended that bra designers enable the straps of encapsulation bras to be easily modified into a cross-back strap orientation to provide females with this strap orientation option if they experience strap slippage.

5. Inserting strap cushions under bra straps has potential to prevent straps from digging into the shoulder of the wearer but only if the cushions are designed to significantly increase the area over which the shoulder strap force is dissipated. It is recommended that bra strap cushions be designed so that they lie flat over the shoulder of the bra wearer to increase the bra strap-shoulder contact area and, in turn, decrease the pressure experience at the bra strap-shoulder interface. Further research is also warranted to look at other strategies to prevent sports bra
straps digging into the shoulders of the bra wearer, such as altering strap width or the material properties of straps, in order to improve sports bra usage when females participate in physical activity.

**FUTURE RESEARCH**

Based on the findings of this current thesis, recommendations for future research are listed below:

1. Educational programs need to be developed and tested to ensure that the scientific findings related to sports bras are translated to the general population, ensuring consideration is given to education content that is specific to breast size, age and purchasing habits.

2. Whether encapsulation bras affect maximal oxygen consumption differently from compression bra types was not within the scope of the present study and warrants further investigation.

3. It is recommended that further investigations assessing the effects of sports bras on other measures of performance, such as cardiovascular function during exercise is undertaken, and that the participant base is expanded to include postpartum women.

4. Further research assessing bra strap cushion design is needed to ensure that these cushions can effectively increase the contact area between the bra strap and the wearer’s shoulder. This will ensure that bra strap cushions can increase the area over which strap forces are applied and, in turn, alleviate the pressure exerted by the bra straps onto the shoulder of the wearer.

5. Although the cross-back shoulder strap design can alleviate the problem of the bra shoulder strap slipping off the shoulder, without negatively affecting breast
support, this design was not comfortable for all wearers. Further investigation into other strap orientations, such as the racer-back or T-bar is therefore warranted to determine whether they can provide adequate support while being comfortable to wear.

6. Although results from this thesis suggested that the pressures measured between the bra and the wearer were not large enough to reduce lung function or overall comfort, further investigations into the effect of bra pressure on blood flow and lymphatic drainage obstructions are warranted.
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Appendix A

Survey Questionnaire

Why Do Women Buy Bras?

Thank you for agreeing to complete this survey. Please work your way through the following questions, ticking boxes where applicable. Where it is stated please specify, please do so with as much detail as possible.

Personal Details
1. What is your age? ________ years

2. What is your post code? ______

3. What is the usual size bra you wear? _______size_______cup

Bra Buying and Fitting
4. Where do you buy your bras? (please tick all that apply)
   - ☐ Department store
   - ☐ Lingerie store
   - ☐ Catalogue
   - ☐ Supermarket
   - ☐ Internet
   - ☐ Factory outlet
   - ☐ Other, please specify _____________________________

5. Do you usually buy your own bras? Yes / No
   If No, who buys them for you?______________________________________

6. What would you currently spend on a fashion bra?
   - ☐ < $20
   - ☐ $20 - $30
   - ☐ $30 - $40
   - ☐ $40 – $50
   - ☐ $50 - $60
   - ☐ > $60

7. What would you currently spend on a sports bra?
   - ☐ < $20
   - ☐ $20 - $30
   - ☐ $30 - $40
   - ☐ $40 – $50
   - ☐ $50 - $60
   - ☐ > $60
8. What would you be prepared to pay for an effective sports bra?

☐ < $20  ☐ $20 - $30  ☐ $30 - $40

☐ $40 - $50  ☐ $50 - $60  ☐ > $60

9. Have you ever been professionally fitted for a bra?  Yes / No

If No, please go to Question 14,
If Yes, please specify how long ago:

☐ < 6 months ago  ☐ 6 – 12 months ago  ☐ 1 – 2 years ago

☐ 2 – 5 years ago  ☐ > 5 years ago

10. Where were you fitted? (please tick all that apply)

☐ Department store  ☐ Lingerie store  ☐ Factory outlet

☐ Other, please specify _____________________________

11. Since you were last fitted for a bra, have any of the following occurred?  Yes  No

(please tick all that apply)

☐ Started taking a contraceptive pill

☐ Stopped taking a contraceptive pill

☐ Fallen pregnant

☐ Change in body weight by 5 kg or more

12. If any of the above did occur, did you notice a change in your breast size?  Yes / No

13. If any of the above did occur, did you buy a new bra of a different size?  Yes / No
Appendices

Breast Pain
14. Do you suffer from breast pain? Yes / No

15. Do you believe that this breast pain is due to: (please tick appropriate)

☐ Breast motion  ☐ Menstruation  ☐ Trauma

☐ Combination

☐ Other, please specify ________________________________

16. How often do you suffer from breast pain? (please tick appropriate)

☐ Daily  ☐ Weekly  ☐ Monthly

☐ Only when I exercise  ☐ Rarely  ☐ Never

Physical Activity
17. What activities do you currently participate in? (please tick all that apply)

☐ Netball  ☐ Jogging  ☐ Swimming

☐ Basketball  ☐ Cycling  ☐ Touch football

☐ Rugby/AFL  ☐ Dancing  ☐ Aerobics

☐ Weight training  ☐ Athletics  ☐ Hockey

☐ Walking  ☐ Tennis  ☐ Squash

☐ Other, please specify ________________________________

18. How would you rate your current activity level? (please tick)

☐ Very Active  ☐ Quite Active  ☐ Moderately Active

☐ Some Activity  ☐ Not Active
19. What do you wear most of the time, when performing the above physical activities? *(please tick box)*

- [ ] Sports Bra
- [ ] Crop Top
- [ ] Normal Bra
- [ ] Sports Bra & Crop Top
- [ ] Normal Bra & Crop Top
- [ ] No Bra
- [ ] Other, please specify ______________________________________

20. What do you classify as a sports bra? *(please circle bra)*

![Bra A](image1.png)  ![Bra B](image2.png)  ![Bra C](image3.png)

**Sports Bras**

21. Have you ever worn a Bra A?  
Yes / No

22. Do you currently wear a Bra A?  
Yes / No

23. If Yes, which brands of Bra A do you usually wear? *(please list)*

*If you do not wear a sports bra please answer the following question and then you have finished the survey. Thank you for your time. If you do wear a sports bra please go to question 25 and continue with the survey.*
24. Why don't you wear a Bra A? *(please tick all that apply)*

- [ ] Do not feel I need to
- [ ] Too expensive
- [ ] Don't like the look
- [ ] Too tight around chest
- [ ] Have never considered wearing one
- [ ] Other, please specify ________________________________

25. Why do you wear a Bra A? *(please tick all that apply)*

- [ ] The look
- [ ] Breast bounce (embarrassment)
- [ ] Breast pain / discomfort
- [ ] Possibility of breast sag
- [ ] Media advertising
- [ ] Support
- [ ] Other, please specify ________________________________


27. Of these, how many do you wear? ________
28. What do you think is important when you are buying a Bra A? (*please tick*)

<table>
<thead>
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<th>FACTOR</th>
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<th>Important</th>
<th>Very Important</th>
</tr>
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<td></td>
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</tr>
<tr>
<td>Cost</td>
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<td></td>
</tr>
<tr>
<td>The Look</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Strap Design</td>
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<tr>
<td>Stitching</td>
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<td></td>
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<tr>
<td>Underwire</td>
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<td></td>
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<tr>
<td>Placement of Fasteners</td>
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<tr>
<td>Fabric</td>
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<td></td>
<td></td>
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<tr>
<td>Brand Name</td>
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<td></td>
</tr>
<tr>
<td>Stopping Breast Movement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease To Put Bra On/Get Off</td>
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<tr>
<td>Colour</td>
<td></td>
<td></td>
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<tr>
<td>Other Factors</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

Please specify___________________________________________
29. What do you dislike about most Bra As on the market? *(please tick)*

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<tbody>
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</tr>
<tr>
<td>Fabric</td>
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<td></td>
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<tr>
<td>Creeping Up</td>
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<tr>
<td>Straps Slipping</td>
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<tr>
<td>Straps cutting in</td>
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<td>Fasteners Digging In</td>
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<td>Brand Name</td>
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<tr>
<td>Other Factors</td>
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<tr>
<td>Please specify</td>
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</tbody>
</table>

30. How long would you keep a Bra A for? *(please tick)*

- [ ] < 6 months
- [ ] 6 – 12 months
- [ ] 1 – 2 years
- [ ] 2 – 5 years
- [ ] > 5 years

31. What factor of your Bra A fails first? *(please comment)*

_____________________________________________________________

Thank you very much for taking the time in completing this survey.
Appendix B

Telephone Script for Survey

Hello, My name is _______. I am calling from the University of Wollongong. We are conducting a mail out survey that is targeted at females between the ages of 20 – 35 years. I was wondering if there was anyone in your household in that age group?

YES
Could I possibly speak to them please?

NO
Thank you for your time.

YES
Hello, My name is _______. I am calling from the University of Wollongong. We are conducting a mail out survey that is targeted at females between the age of 20 – 35 years to find out why women buy bras and what features of a sports bra women like and dislike. If you agree to do the survey, I will post it out to you this week, and it should only take you 5 – 10 minutes to complete. I will also send you a stamped self-addressed envelope to return the survey in so that it will not cost you anything. By completing and returning the survey, you will be entered into a draw to win $200 worth of lingerie. Can I send you a copy of the survey?

NO or Not here.
Would you know of a more convenient time when I could contact her? Can I possibly get her name so that I can ask for her next time I call? Thank you for your time.

YES
Thank you. Who should I address that to? Can I please get your address? I will mail the survey out to you this week. Thank you for your time.

NO
Thank you for your time.
Appendix C

Professional Bra Fitting Instructions

This procedure involved a girth measurement taken around the torso of the female, just below the level of the breast line (see figure below), with no restriction around the torso of the subject. A bra may be worn but should not be attached at the back to interfere with under bust measurements.

The Berlei Body Consulting Workshop Fitting Manual suggests that the tape measure should be placed around the torso to provide a “firm and snug under bust measurement”. The recommendation is that the tape measure should be held “as firmly as you expect the bra to feel on the body.” All measures are taken in inches with the following five steps recommended in the fitting manual;

1. Take the tape measure and hold it with the inches facing out.
2. Find the halfway point of the measurement you think the subjects is an place the halfway point at the centre of the subjects back
3. Bring one side at a time around to under the arm. Stop at this point and give a nice firm pull on the tape measure. This will ensure you will not loose the tension in the measure
4. One side at a time, bring the tape measure around to the front of the bust, making sure you do not have the tape measure over the bra and underwire (this will increase the measurement). Use your thumbs to guide you through this last step, as you need the tape measure to remain firm and snug around the body.
5. Now read the inch measurement. Take a look at your chart to see what size the subjects is.

After the girth measurement is recorded, the fitter should refer to the fitting table to suggested a torso size. The subject should initially be provided with a bra of the suggested torso size, however the subjects may feel that the bra is either too tight or too loose, in which the next size either way should be provided. Breast cup is visually estimated with the fitter then suggesting a range of sizes to the customer.
<table>
<thead>
<tr>
<th>Inches</th>
<th>European</th>
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<tbody>
<tr>
<td>Size 10</td>
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<tr>
<td>Size 12</td>
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</table>

(Berlei, Body Consulting Workshop Manual, 2000)
Appendix D

Pulmonary Function and Physical Activity Questionnaire

Applied Physiology Research Laboratory
Department of Biomedical Science
University of Wollongong

Please answer the questions as frankly and accurately as possible. ALL INFORMATION OBTAINED IN THIS STUDY WILL BE KEPT CONFIDENTIAL AND USED FOR THIS RESEARCH PROJECT ONLY.

NAME:..................................................................................................................

RESEARCH ID CODE:.......................... DATE:.................................................

ADDRESS:...........................................................................................................

DATE OF BIRTH:........................................... AGE:................................. yrs

GENDER: ( ) male ( ) female

BODY MASS:................................. kg  HEIGHT:......................... cm

OCCUPATIONAL HISTORY:

Your current occupation or job: .................................................................

Have you ever worked in or been exposed to:

( ) dusty jobs ( ) smoke jobs ( ) gas fumes ( ) chemical fumes

Please specify total period of this work: ......................... Yrs

MEDICAL HISTORY:

Do you have any of these illnesses?

( ) heart problem, please indicate the physician’s diagnosis:.........................

first incident at age:...........yrs, last incident on ............... (dd/mm/yyyy) date

( ) respiratory (lung) problem, please indicate the physician’s diagnosis:...........

first incident at age:...........yrs, last incident on ............... (dd/mm/yyyy) date
( ) others (please indicate: high blood pressure, muscle, bone, neural disorders, operation, diabetic problem etc): …………………………………………

Your doctor’s address and telephone number:
……………………………………………………………………………………………

Current medications (prescribed by physician):
…………………………………..

Do you have any medical conditions, which you feel the current researcher should be made aware of? ( ) no ( ) yes, if yes: ………………………………
………………………………………………………………………………………….

Has your doctor ever said you have a heart condition and recommended only medically supervised physical activity? ( ) yes ( ) no

Do you have chest pain brought on by physical activity? ( ) yes ( ) no

Have you developed chest pain within the past month? ( ) yes ( ) no

Do you tend to lose consciousness or fall over as a result of unexplained dizziness? ( ) yes ( ) no

Has a doctor ever recommended medical for your blood pressure or a heart condition? ( ) yes ( ) no

Do you have a bone or joint problems that could be aggravated by the proposed physical activity? ( ) yes ( ) no

Are you aware, through your own experience or a doctor’s advice, of any other physical reason against your exercising without medical supervision? ( ) yes ( ) no

SMOKING HISTORY:
Have you ever smoked cigarettes? ( ) yes ( ) no
(no means less than 20 packs in a lifetime or less than 1 cigarette a day for a year)

If the above answer is “yes”, do you now smoke cigarettes (as of a month ago)? ( ) yes ( ) no

How old were you when you first started regular smoking? : …………….. Yrs

How many cigarettes do you smoke per day now? ……………………..

If you have stopped smoking completely, how old were you when you stopped? ………….. yrs
PHYSICAL ACTIVITY HISTORY:
On average, how frequently are you engaged in physical exercise: (such as: running, walking, swimming, cycling, playing active sports etc.)
( ) less than once per week
( ) once per week
( ) 2-3 times per week
( ) 4-6 times per week
( ) at least once per day

Do you consider yourself to be sedentary? ( ) yes ( ) no
(exercising once or less per week for the last ten years, or form more than 2 years continuously since turning 20 years)

Do you consider yourself to be habitually active? ( ) no ( ) yes
(you are currently active, you have a long history of regular physical activity since turning 20 years, for more than 10 years, and you exercise more than 3 times per week at an intensity greater than 50% of maximal capacity)

On average, how frequently do you perform endurance exercise at an intensity which is about 65% or more of your maximal capacity, for more than 30 minutes at a time?
( ) rarely
( ) less than once per week
( ) once per week
( ) about 3 times per week
( ) more than 4 times per week

Have you ever experienced unexplained chest pain during exercise? ( ) yes ( ) no

Do you have to walk slower than people of your age because of breathlessness? ( ) yes ( ) no

Do you ever have to stop for breath when:
( ) walking at your own pace on the level ground
( ) after walking about 100 yards on level ground
( ) walking up a slight hill
( ) dressing and undressing
( ) gardening
( ) other, please indicate: .................................................................

Do you usually cough on getting up, or first thing in the morning? ( ) yes ( ) no

Do you usually cough during the day or at night? ( ) yes ( ) no
If yes, do you usually cough like this on most days for 3 consecutive months or more during the year? ( ) yes ( ) no
If yes, for how many years have you had this cough? ....................yrs
Appendices

Do you usually cough up phlegm on getting up, or first thing in the morning? ( ) yes ( ) no

Do you usually cough up phlegm during the day or at night? ( ) yes ( ) no

If yes, do you usually cough up phlegm like this on most days for 3 consecutive months or more during the year? ( ) yes ( ) no

If yes, for how many years have you had trouble with phlegm? ........... yrs

Does your chest ever sound wheezy or whistling? ( ) yes ( ) no

If you have a chest wheeze or whistling, for how many years has it been present? ...................... yrs

Have you ever had an attack of wheezing that has made you feel short or breath? ( ) yes ( ) no

Have you ever required medicine or treatment for such an attack of wheezing? ( ) yes ( ) no

References:
Appendix E

Subjective Questions for Qualitative Assessment of the Two Bra Styles

The following 10 questions were asked to each subject after all sub-maximal exercise trials were completed.

1. What do you usually wear for breast support during exercise?
2. If you had to choose one of the two bras to exercise in which would you choose?
3. Why would you choose that bra?
4. Did the fashion bra feel that it affected your ability to exercise in any way?
5. Did the sports bra feel that it affected your ability to exercise in any way?
6. Did the fashion bra feel that it affected your ability to breath in any way?
7. Did the sports bra feel that it affected your ability to breath in any way?
8. Is this the bra size you would usually wear?
9. Have you ever been professionally fitted for a bra before this experiment? When were you fitted?
10. Do you currently own either if the bras you wore today?
Appendix F

Subjective Questions Assessing Overall Bra Comfort and Preferred Shoulder Strap Configuration

1. Do you suffer from pain in the neck region?
2. Have you ever sought treatment for this pain?
3. What do you believe this pain is due to?
4. Do you suffer from pain in your shoulders?
5. Have you ever sought treatment for this pain?
6. What do you believe this pain is due to?
7. Do you suffer from pain in your arms?
8. Have you ever sought treatment for this pain?
9. What do you believe this pain is due to?
10. Have you ever experienced tingling or numbness in your little finger?
11. If so, what do you think caused it?
12. Do you suffer from headaches?
13. Have you ever sought treatment for this?
14. What do you believe this pain is due to?
15. Of the bra set ups used today, which do you feel was the most comfortable?
16. Did any of the set ups impede your ability to exercise?
17. Have you ever worn this bra before?
18. Have you ever been professional fitted for a bra prior to this study? When?
19. Do you have any other general comments?